Jos. S. Henry

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PAPERS

Paper No. 133

ECONOMICS OF ELECTRIC POWER STATION DESIGN.

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Papers heretofore written on power station design are generally descriptive and relate to the size and arrangement of the generating units, boilers, etc. Such papers have been of little lasting value principally because of the radical changes that have occurred in connection with size and type of prime movers. For a given kilowatt output to-day, there is no great range of choice in prime movers, since engineers are agreed that turbines possess the balance of advantages. Questions as regards economy in turbines do not arise in the same way as they do in respect to condensing or fuel economy apparatus, since the efficiency of the turbine of given rating would not be a function of the cost. The broad question arising in respect to the turbine is as to the extent centralization may take place and justify the use of larger turbines with the attendant economies. For the specific apparatus of obtaining economies, the extent of which is dependent upon the amount of plant used and the attendant investment, the load factor or the cost of fuel per kilowatt per annum are the determining factors. The economies gained by centralization have to be balanced against the cost of mains in linking up from a central source of supply with different distribution centres. The present paper deals with the constants involved in this general problem and, as illustrative of the nature of the problem, particulars are given of the electric supply of London.

The design of a Power Station may be considered from two points of view, one, which may be termed the mechanical, relating to type and arrangement of plant, and the other, the

economical, involving the balancing of capital against the economies effected by the use of various amounts or types of plant upon which the consumption of fuel depends either directly or indirectly.

From time to time, the author has published details of power plants that he has designed, but upon looking over these publications it appears that, owing to the progress in design of prime movers and the different conditions regulating generation brought about by improvements in electrical methods, such descriptions have little lasting value, and can only be of permanent interest when regarded from the standpoint of economic design.

It is the purpose of this paper to discuss power station design from the economical point of view, and the various aspects will be considered from the general principle that the amount of capital that can be used in effecting any economy in generation is proportional to the number of hours in the year during which such economy can be realized.

An attempt is made to show the properties of the plant under different conditions of operation and wherever possible curves have been established showing under what conditions the installation can be operated to the best advantage,—material, labour, maintenance and capital being considered.

In order to establish a basis from which the effect of varying conditions may be determined, the operating and capital costs are given for modern power stations designed to give the most economical results under certain assumed conditions, but for the reasons given above, such examples must be taken as only generally illustrative and not what the author might consider applicable to every case.

Fig. 1 shows the total capital cost of such modern power stations per kilowatt installed. Although these figures will vary with the locality and market conditions generally, and may be considered on the high side, they are consistent throughout the range of sizes and load factors considered and therefore do not affect the resulting conclusions when viewed as a comparison between varying conditions.

Fig. 2 shows the overall thermal efficiencies which may be expected from modern stations of various sizes and load fac-

Fig 1.

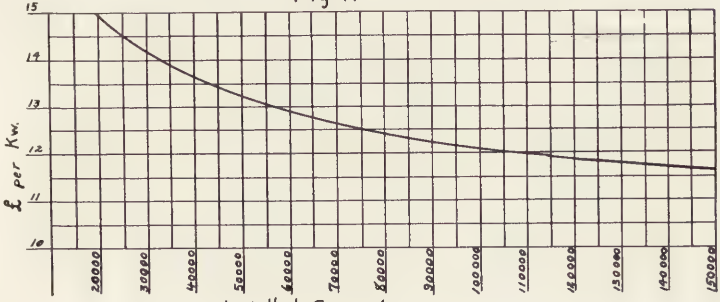


Fig. 2.

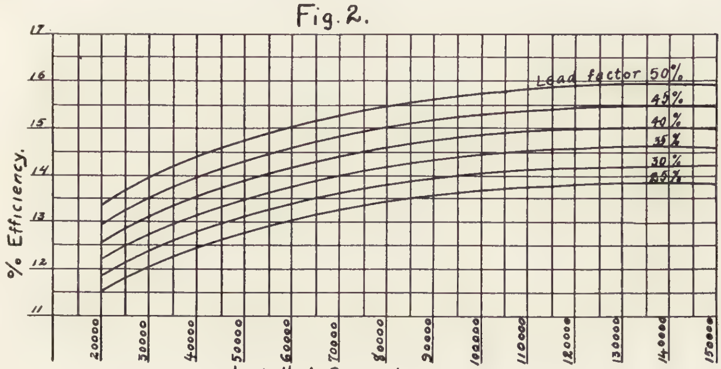
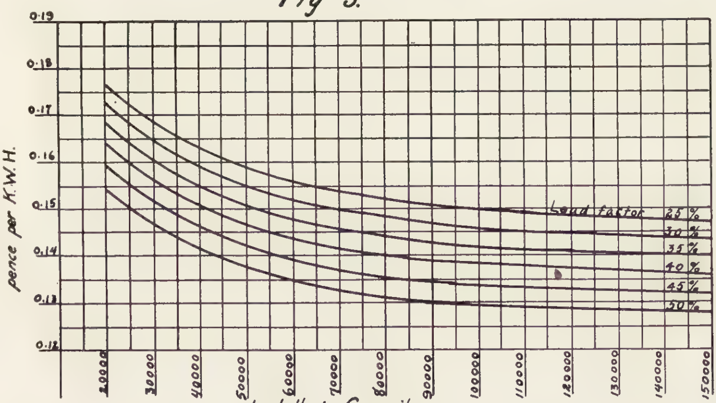


Fig 3.



Note: In Figs. 1 to 6 inclusive "Installed Capacity" is in kilowatts.

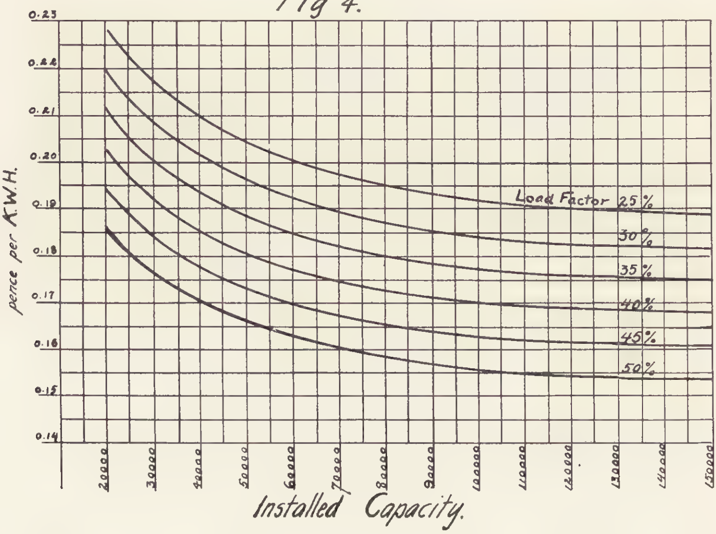
tors. The steam conditions assumed are pressure 175 lbs. gauge, vacuum 28½″ (Bar. 30″) and superheat 100°F. and it is assumed that the station is equipped with five generating units.

Fig. 3 shows the coal costs derived from the thermal efficiencies given on Fig. 2 with coal at 14/- per ton, the calorific value assumed being 12,500 B.T.U. per lb.

The total costs (Fig. 4) are based upon a ratio of coal to total costs taken from the actual results of modern stations.

The capital charges per unit shown on Fig. 5 are calculated

Fig 4.



from Fig. 1 on a 10% basis, the maximum load being taken as 80% of the installed capacity for all sizes of stations.

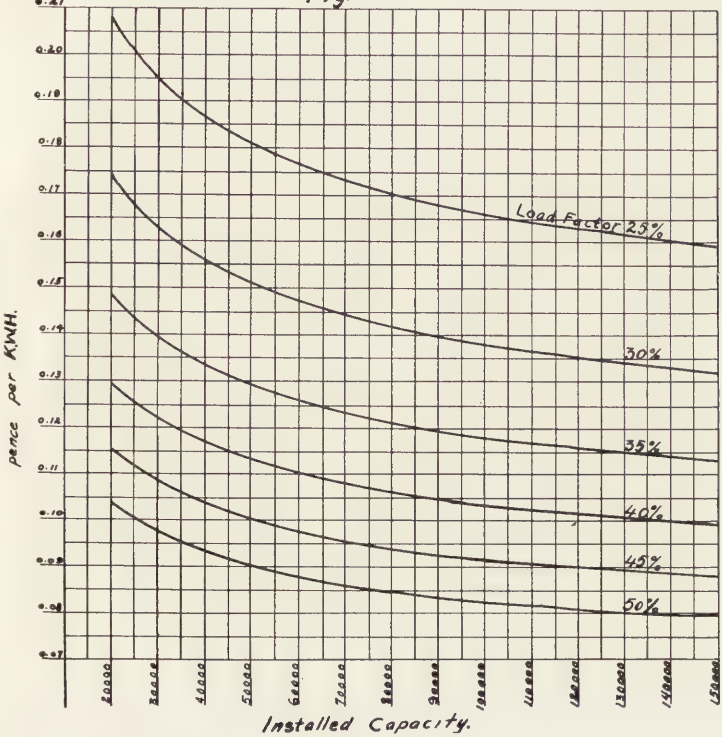
Fig. 6 shows the sum of operating (Fig. 4) and capital costs (Fig. 5) and the result may be taken as indicative of the improvement to be expected from the centralization of generation and increase of load factor.

These results are shown on Fig. 7, expressed as comparative costs, the ordinate scale being purely arbitrary and indicating the relative total cost under varying conditions. Expressed in this manner only two curves are necessary, since the relative costs with varying sizes of station are constant for any load

factor and the relative costs with varying load factors are constant for any size of station.

An important consideration in the design of a modern generating station is the selection of the site, the chief consideration in this respect being coaling and condensing facilities. It will usually be found that a site with good condensing facilities will also be most convenient for coaling, but such a site is

Fig. 5.



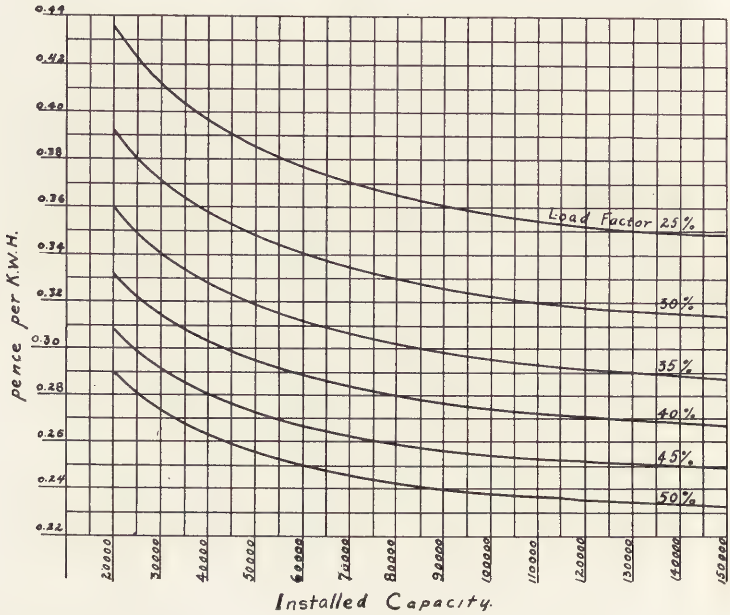
generally difficult to obtain near to the area of supply and so the question arises as to how far it is expedient to go from the area of supply in order to secure the most efficient generation. This involves the balancing of the cost of transmission against the saving to be effected and the distance will be determined chiefly by the load factor. Many other considerations enter into the question, but as these vary but little, and as the effect

of such variation upon the economical distance is so slight, values have been assigned which in the author's experience are most likely to obtain.

The cost of transmission includes maintenance, energy loss and 10% on the cost of mains.

The cost of cables per mile laid under average conditions is taken uniformly at 12/- per kilowatt of maximum load, and the energy loss is calculated upon the assumption of 20,000

Fig 6.



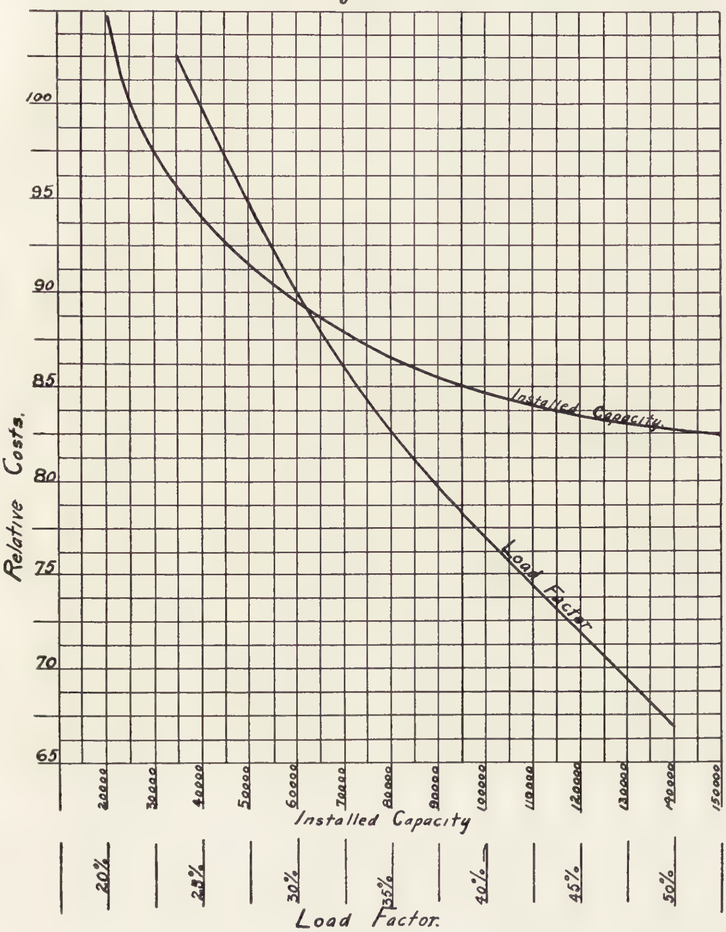
volt transmission and 500 amperes per square inch maximum working current density at 0.8 power factor.

Upon these values the total annual cost of transmission works out at 16.5d per mile per kilowatt of maximum load and is practically constant for any load factor or maximum load.

The saving to be effected includes the saving in generation, price of coal, water lost in cooling towers, and 10% upon the cost of cooling plant. For this purpose it is assumed that the vacuum is increased from 27 to 28½ and that the price of coal is reduced from 15/- to 14/- per ton.

The efficiency of the Rankine steam cycle at 27″ vacuum is 0.924 of the efficiency at 28½″ supposing the pressure to be 175 lbs. and the superheat 100°F. and this ratio can be applied

Fig 7.



direct to the overall station efficiency. The annual saving per kilowatt due to the increased vacuum and reduced price of coal will, therefore, be given by $\left(\frac{d_1 - d_2}{0.924}\right) \frac{3415 \times 8760 \text{ L. F.}}{\text{E C}}$

where E = efficiency of station at 28½″ vacuum; L.F. = load

factor, d_1 and d_2 = price per lb. of fuel in the respective cases and C = calorific value per lb.

Taking C at 12,500 the saving is $\frac{28.557 \text{ L. F.}}{\text{E}}$

The saving in cooling plant is taken at 10% on £1 per kilowatt = 24 pence per kilowatt of maximum load.

The cost of the water evaporated by the cooling towers and saved by a riverside station is based upon an evaporation of 15 lbs. of water per kilowatt hour at 6 pence per 1000 gallons and the annual saving in pence per kilowatt of maximum load is given by $\frac{15 \times 6 \times 8{,}760 \text{ L. F.}}{10 \times 1000} = 78.84 \text{ L. F.}$

The total saving due to the improved site is then $\frac{28.5 \text{ L.F.}}{\text{E}}$ $+ 24 + 78.84$ L.F. and it will be seen that the saving will fall slightly as the station efficiency increases.

Assuming a station efficiency of 12% and the total annual cost of transmission being 16.5d per kilowatt mile, the distance at which the saving balances the cost of transmission is given by

$$\frac{24 + 317 \text{ L.F.}}{16.5} = 1.45 + 19.21 \text{ L.F.}$$

These distances are plotted on Fig. 8 for varying load factors.

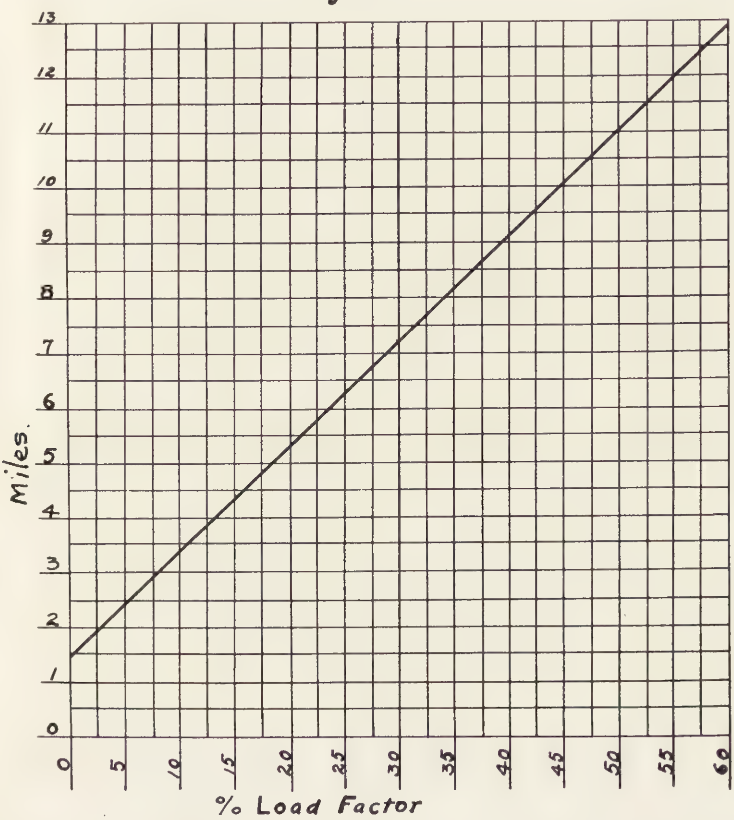
No account has been taken of rates and taxes or site values since these vary so widely that no particular figure can safely be assumed. When it is considered that the additional land required for cooling towers is usually in the most expensive area, it may easily be that the saving in site values may double the economical distance given.

The determination of the steam and exhaust conditions under which a station should operate, is also, although more complicated, a matter of balancing the saving in fuel cost against the cost of effecting such saving. While the effect of any variation in the steam conditions upon the operating costs may be determined with a fair degree of accuracy, the variation in the capital cost is a matter which must be determined according to the conditions prevailing in each individual case. The saving to be expected with varying steam conditions is there-

fore presented, from which the capital that can be properly spent in effecting any improvement may be easily determined.

The effect of variation of either pressure, vacuum or superheat upon the efficiency of the Rankine steam cycle is to increase or decrease such efficiency by a definite amount whatever the

Fig. 8.

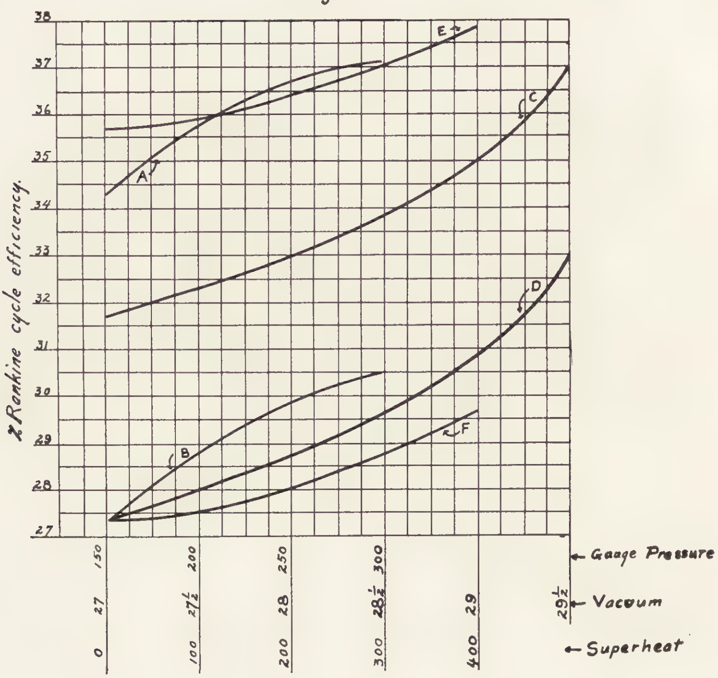


value of the other two conditions may be. This is shown in Fig. 9, where the efficiencies corresponding to the variation of any one condition are shown for two extreme values of the other two. For instance, the efficiency with varying pressure is shown for 27″ vacuum and no superheat, and also for 29½″ vacuum and 300°F. superheat, and similar curves for varying

pressure for any values of vacuum or superheat between these limits would fall between and be parallel to these two curves.

It will be seen that any improvement in any one condition results in an addition to the Rankine cycle efficiency and that

Fig. 9.



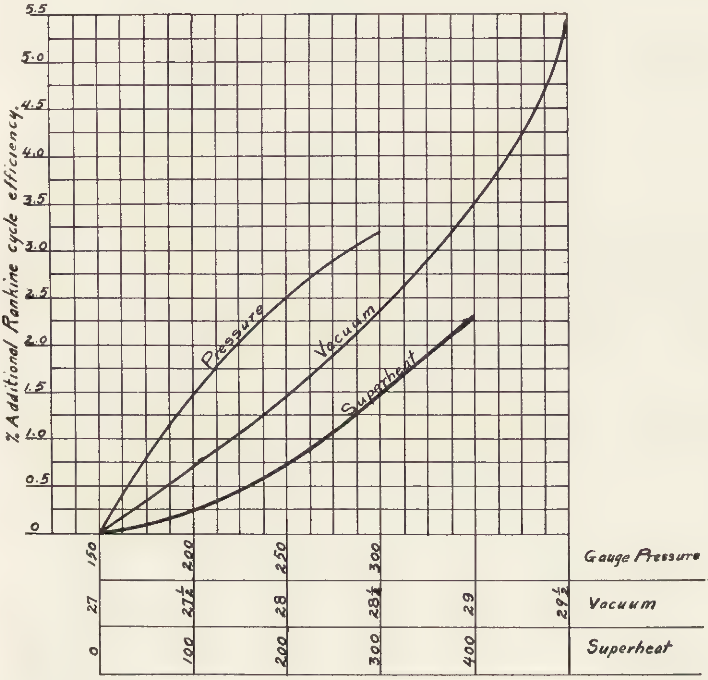
A.	Varying pressure	300° superheat	29½" vacuum.	
B	" "	0° "	27" "	
C	" Vacuum	300° "	275 lbs. pressure	
D.	" "	0° "	150 " "	
E.	" Superheat	29½" Vacuum	275 " "	
F.	"	27 "	150 " "	

such addition remains constant whatever the original efficiency may have been. An improvement may therefore be expressed as on Fig. 10, which gives the additional efficiency due to variation of any one of the three conditions, and each curve is correct for any values of the remaining two conditions assuming

that the latter remain constant throughout the variation under consideration.

Such improvement, expressed as a proportion, may be applied direct to the overall efficiency of the station, since, apart from the steam cycle, the efficiency of the rest of the plant in any given station will remain practically constant under any

Fig. 10.



variation in steam conditions if designed to meet such conditions.

Since it is impossible to express the results on Fig. 10 as a proportional improvement, unless the other two conditions are known, and impracticable to present general conclusions covering all possible combinations, the steam conditions adopted in the construction of Fig. 2 are employed as a standard, and Figs. 11, 12 and 13 have been prepared showing the annual saving to be expected from any variation in the steam conditions. In the construction of these curves the overall station efficiency

Fig. 11.

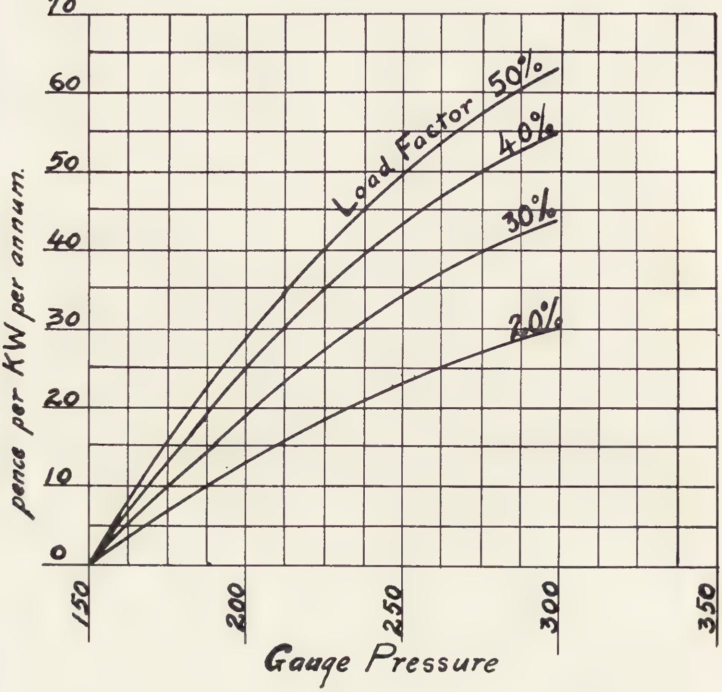
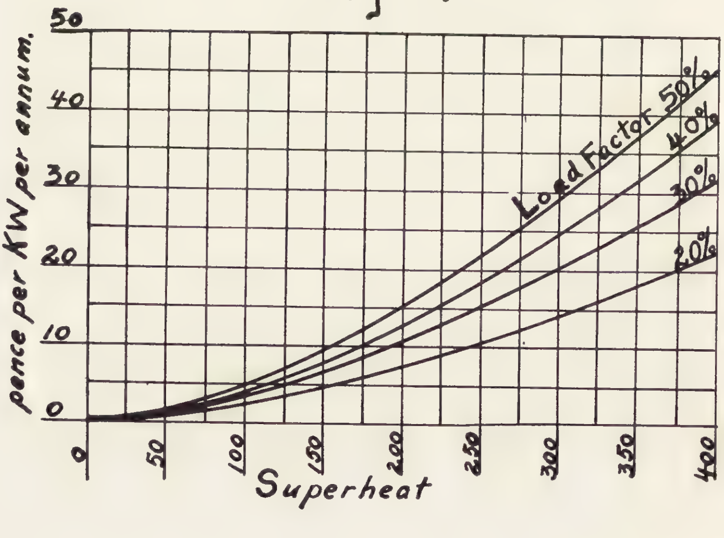
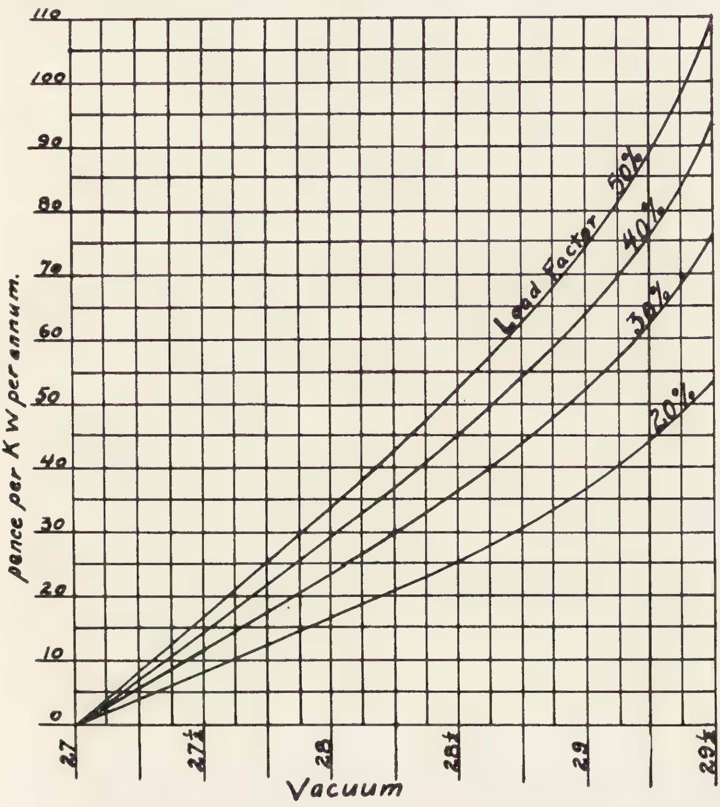

70
60
50
40
30
20
10
0
pence per KW per annum.
Load Factor 50%
40%
30%
20%
150
200
250
300
350
Gauge Pressure

Fig. 12.


50
40
30
20
10
0
pence per KW per annum.
Load Factor 50%
40%
30%
20%
0
50
100
150
200
250
300
350
400
Superheat

assumed under these conditions is 13% at 40% load factor and the price of coal 14/- per ton with 12,500 B.T.U. calorific value; inversely with the overall station efficiency and with the results shown will, of course, vary the price of coal.

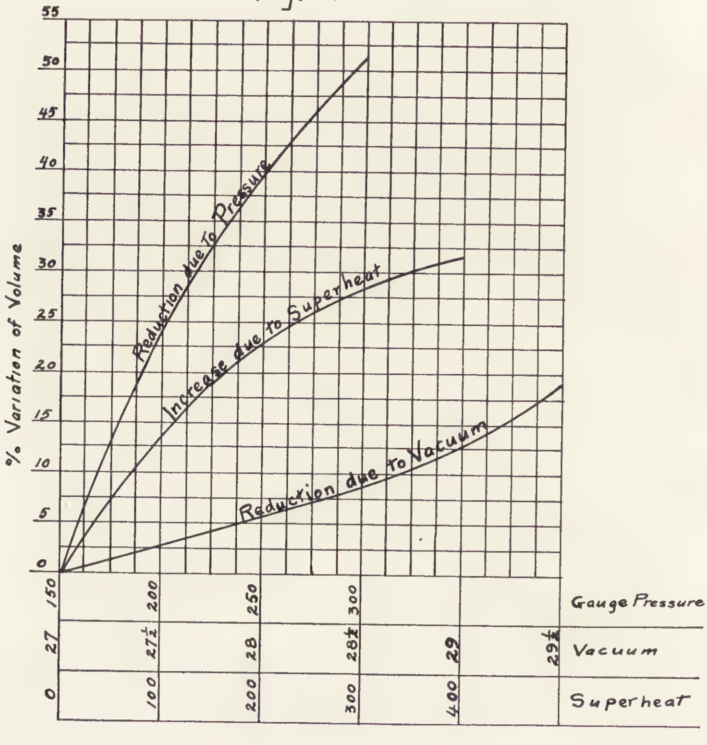
Fig. 13.



Although close calculation for any particular case may give results varying slightly from those shown, the figures for general purposes are sufficient to indicate the amount of capital which can be profitably employed in increasing the degree of either pressure, vacuum or superheat, always assuming that the plant is to be designed to meet the conditions finally decided upon.

Capital expenditure will increase considerably with increase of vacuum and depends upon the cooling water temperature, but in the case of pressure and superheat the increase in capital expenditure is practically confined to the increased size of pipes and valves up to the point where increased pressure involves a departure from standard boiler designs or increased superheat calls for a separately fired superheater. These values

Fig. 14.

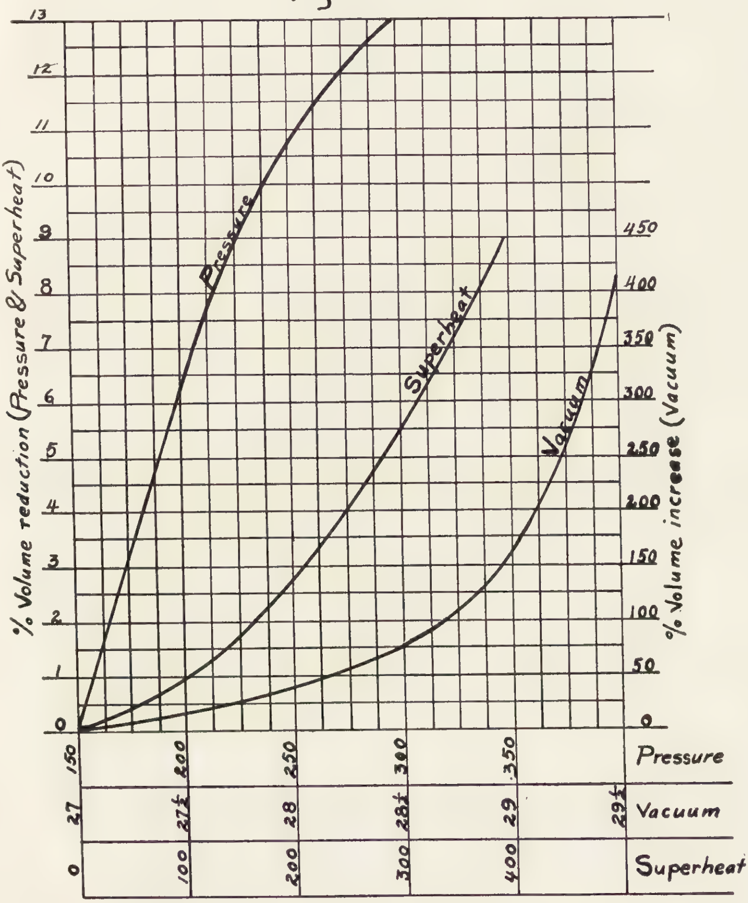


are in the neighbourhood of 250 lbs. pressure and 200° superheat. The cost may be ascertained for any individual case, but in the author's opinion the economic benefit is, in the majority of cases, at a maximum at these values.

With regard to increased size of piping and valves it is convenient to note that any increase of either pressure, vacuum or superheat results in a variation in the volume of steam per

kilowatt hour and that when considering any one condition, variation in volume can be expressed as a definite proportion of the original volume either at the pressure or exhaust end of the turbine, whatever the values of the other two conditions may be.

Fig. 15.



Figs. 14 and 15 show respectively percentage variation in volume of high pressure steam and exhaust for variations in any of the steam conditions and each curve is correct for any values of the remaining two conditions.

Another feature of power station design, which may be determined by balancing capital charges against the saving is the economiser installation. A considerable number of variables enter into this investigation, the determination of the economical economiser surface involving the consideration of the following conditions:

E. Overall efficiency of Generating Station.
L. Load factor.
d. The price of fuel.
h. The proportion of fuel heat leaving the boiler in the products of combustion.
T_1. Temperature of flue gases entering the economiser.
T_2. Temperature of flue gases leaving the economiser.
ta. Temperature of air entering furnace.
W. Water fed to economiser per kilowatt hour.
t_1. Temperature of water fed to economiser.
H. Rate of heat transference through economiser.
C. Cost of economiser surface.

Neglecting radiation losses in the economiser and assuming that the whole of the heat represented by the temperature drop in the flue gases is transferred to the water, the economiser surface in sq. ft. per kilowatt of maximum load will be given by

$$\frac{6830\ h(T_1 - T_2)}{E\ H(T_1 - ta)\left(T_1 + T_2 - 2t_1 - \dfrac{3415h(T_1 - T_2)}{E\ W(T_1 - ta)}\right)}$$

where H = heat units per square foot per hour per degree mean difference of temperature and W = lbs. per kilowatt hour.

The annual capital charge on a 10% basis will be represented by

$$\frac{16392\ Ch(T_1 - T_2)}{E\ H(T_1 - ta)\left(T_1 + T_2 - 2t_1 - \dfrac{3415h(T_1 - T_2)}{E\ W(T_1 - ta)}\right)}$$

where C is £ per tube of 10 sq. ft. installed complete.

The annual saving is as follows:

$$\frac{29{,}915{,}400\ L\ h(T_1 - T_2)}{E\ d\ (T_1 - ta)}$$

where d is expressed as heat units per 1d.

Many of the conditions do not vary to any appreciable extent in any installation and, as the object of this investigation, viz., the determination of the most economical surface, will not be appreciably affected by the slight variations which may exist, the following values may be assigned

$h = 0.2$, $T_1 = 500$ $ta = 60$

$C = 2$, $H = 3$ $W = 20$

$d = 167{,}000$

With these values fixed, the expressions given above become

$$\frac{1.035(500 - T_2)}{\left(E\,500 + T_2 - 2t_1 - \dfrac{500 - T_2}{12.88\ E}\right)} = \text{sq. ft. surface per kilowatt of maximum load}$$

$$\frac{4.96\ (500 - T_2)}{E\left(500 + T_2 - 2t_1 - \dfrac{500 - T_2}{12.88\ E}\right)} = \text{Capital charge in pence per annum per kilowatt of maximum load}$$

$$\frac{0.0814\,(500 - T_2)\,L}{E} = \text{Annual saving in pence per kilowatt of maximum load}$$

Fig. 16 shows the surface in terms of t_1 and T_2 and the value of E is fixed at 0.12.

Fig. 17 shows the same with E fixed at 0.15.

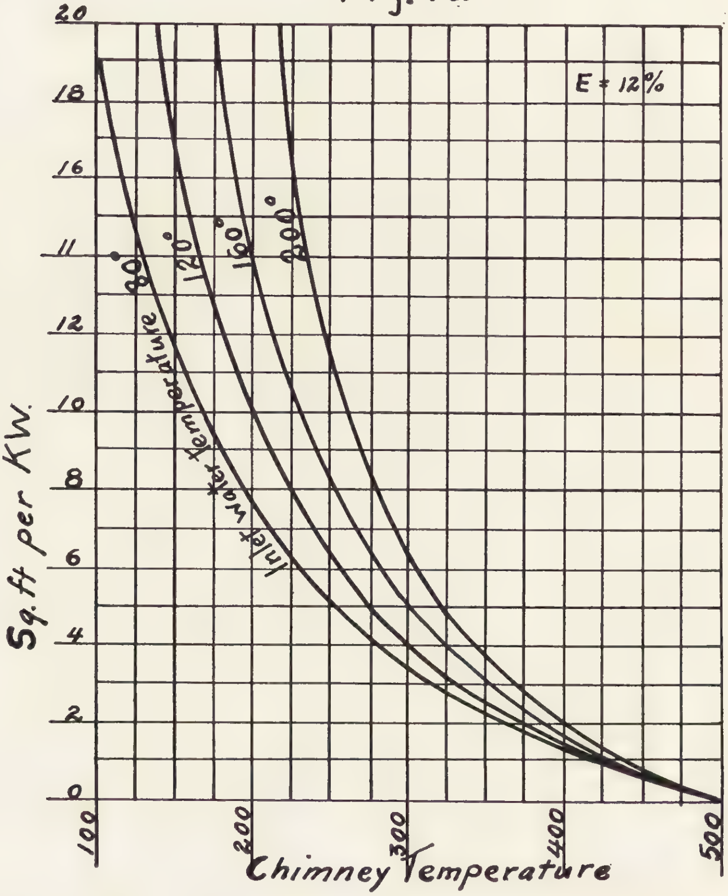
The annual saving to be effected for any given value of E varies with load factor and chimney temperature, and the surface (upon which the capital charge depends) varies with chimney temperature and inlet water temperature. It will, therefore, be seen that, in order to plot the annual saving against the surface, separate curves would be necessary for load factors and inlet water temperatures and in order to avoid crowding the curve sheet the annual saving is plotted on Figs. 18 and 19 against the chimney temperatures, for $E = 0.12$ and 0.15 respectively and the corresponding surface can then be read from Figs. 16 and 17.

When considering annual saving, it must be noted that, with a given economiser installation any reduction in load will result in a drop in chimney temperature if the whole of the feed water is passed through the economiser. The chimney temperature however may be kept constant by bye-passing a portion of the feed water to an extent where the decreased dif-

ference of temperature balances the increased surface per kilowatt of load.

Figs. 18 and 19 are based upon the latter assumption, since with natural draught, the chimney temperature must be kept

Fig. 16.



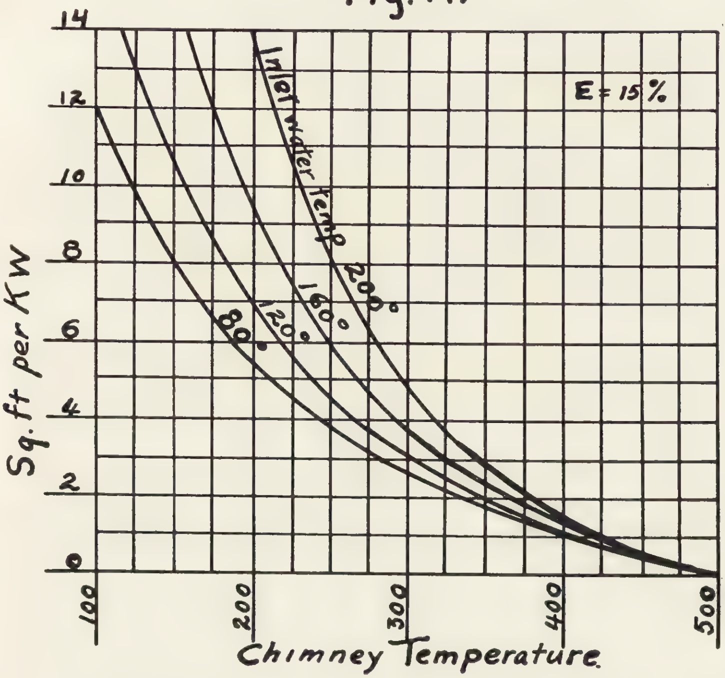
more or less constant, and it will be seen later that forced draught is not an economical proposition except with extremely high load factors.

From these curves it is possible to balance the capital charges against the annual saving. Figs. 20 and 21 show the

gain or loss with varying surface, inlet water temperatures and load factors for 0.12 and 0.15 respectively as values of E, the zero line indicating the point at which capital charge balances annual saving.

Upon these curves (20 and 21) a line has been drawn for each load factor at the point where the flue gases stand at 300° and to right of these lines (marked A) artificial draught would

Fig. 17.



become necessary involving capital expenditure beyond that taken into consideration and reducing the saving by the cost of producing artificial draught. A curve (marked B) has also been drawn through the points of maximum economy. These points have been plotted on Fig. 22, which shows at a glance the economical surface for any given load factor and inlet water temperature and the manner in which the same varies with the station efficiency. On this sheet also curves (marked A) have

Fig. 18

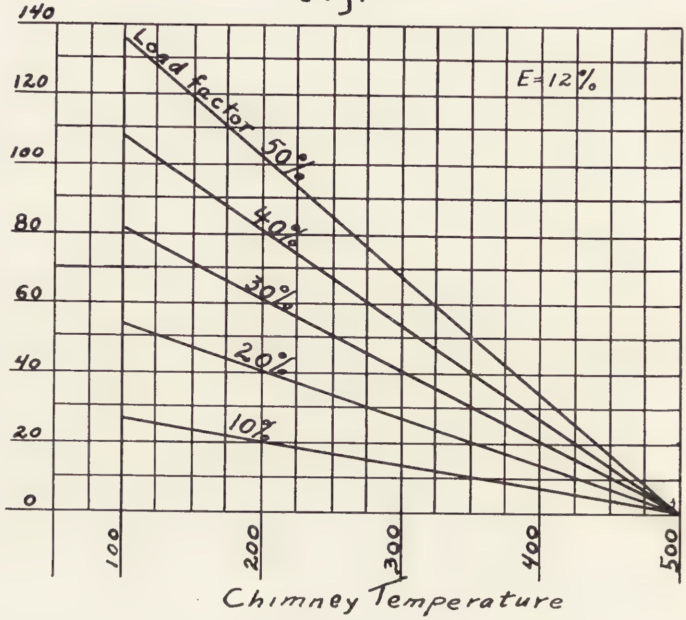

140
120
100
80
60
40
20
0
pence per KW per annum
Load factor 50%
40%
30%
20%
10%
E=12%
100
200
300
400
500
Chimney Temperature

Fig. 19

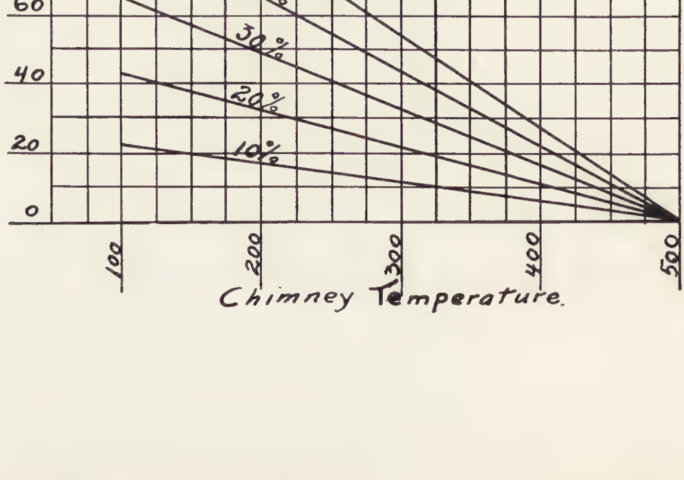
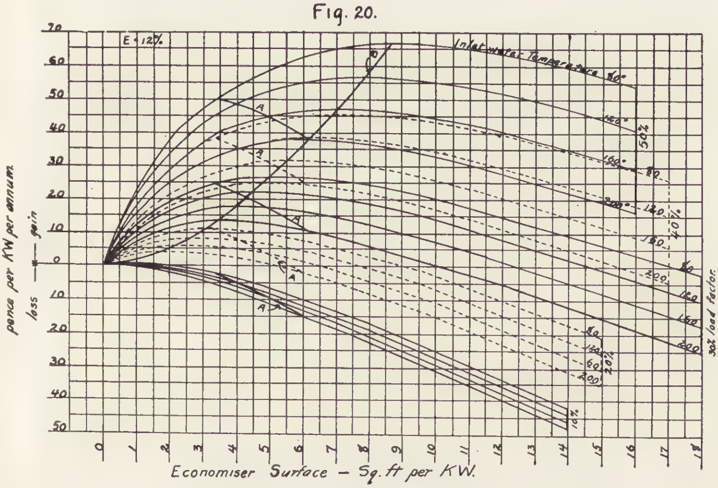

120
100
80
60
40
20
0
pence per KW per annum
Load factor 50%
40%
30%
20%
10%
E= 15%
100
200
300
400
500
Chimney Temperature.

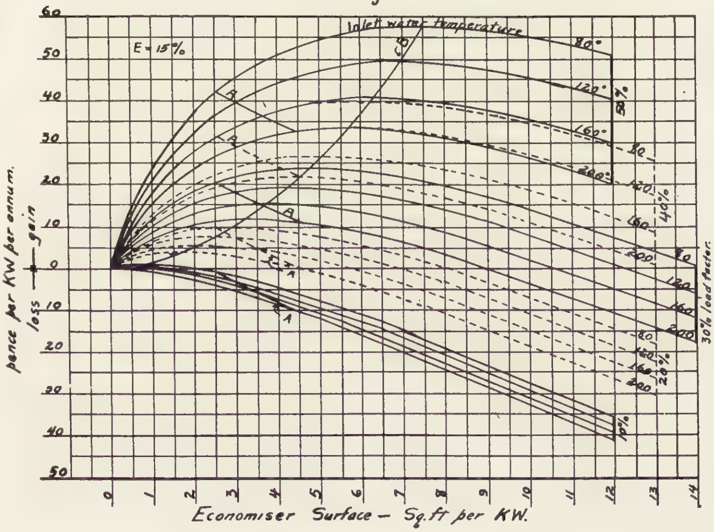
Fig. 20.



been drawn corresponding to a chimney temperature of 300°F. and above these lines artificial draught is necessary.

An examination of these curves (20, 21 and 22) will show that the installation of an economiser becomes a doubtful improvement at 10% load factor, and that artificial draught is of

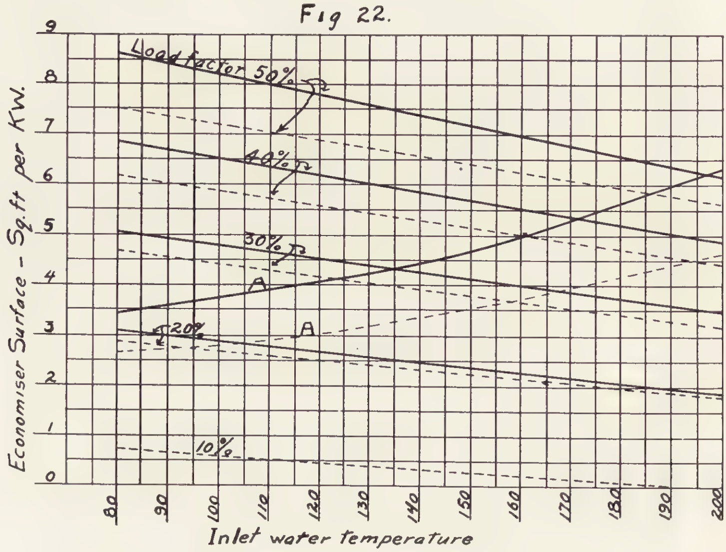
Fig 21.



doubtful value unless the load factor is above 40%, as the increased expense would reduce the economical surface. It should be noted that the curves (20 and 21) are based on a fuel price of 167,000 B.T.U. per 1d, and that while the saving would vary directly and the loss inversely as the price of fuel, the economical point would be unaffected and Fig. 22 is, therefore, independent of the coal cost.

From Figs. 20 and 21 it will be seen that the inlet temperature of the feed water considerably affects the economiser in-

Fig 22.



Full lines. E = 12%
Dotted " E = 15%

stallation and consequently has an important bearing upon the commercial result due to the prevailing practice of heating feed water by means of exhaust from auxiliary plant. It is often urged that turbine driven auxiliaries when exhausting to a feed heater are most efficient, since the latent heat is returned to the system in the feed water. Such efficiency is more apparent than real, as with increased feed water temperature, the saving due to the economiser must be considerably less, capital cost considered. The exhaust from turbine auxiliaries would raise the temperature of the feed water by approximately 100°F., and,

supposing the original temperature at the economiser inlet to be 100°F., the annual saving by economiser will be reduced by about 18d per annum for every kilowatt of maximum load at 40% load factor. This is shown on Fig. 20 and must be set against the apparent thermal efficiency of the auxiliary steam cycle.

Another method is to exhaust the auxiliaries into the main turbine at atmospheric pressure, thus increasing the available heat by expanding to condenser pressure. Considering the inefficiency of the high pressure stage of expansion, it is doubtful whether this arrangement has any advantage over electrically driven auxiliaries when the latter are properly arranged.

It is now common practice to drive the exciter direct from the main turbine shaft and the author is of opinion that in the majority of cases it would be advantageous if such a machine could be designed with sufficient output to drive the auxiliaries in addition to excitation. With a common D.C. busbar and a small independent D.C. set as standby this arrangement would be convenient to operate, would obviate the necessity for steam piping and the attendant fittings and, the necessary current being generated direct by the main turbine, would compare favourably in efficiency with any arrangement of turbine driven auxiliaries in the case of stations with units above 5000 K.W. rating.

With regard to the general layout of power stations, the progress in the development of the engine room has taken place with practically no alteration in boiler room practice so that although the general design of power stations is considerably affected by the available coaling and condensing conditions, the considerations of floor space and piping have practically standardized the right angle boiler room, and the principles underlying the general arrangement of plant are too well known to call for comment.

The development of rotary apparatus for all purposes has long since passed the experimental stage and reciprocating machinery should find no place in the modern power station.

From the foregoing it will be seen that to secure the highest economy in generation, centralization on a large scale is an

economic necessity. The figures given as regards the cost of mains will show that under present day working conditions the cost of electric transmission does not affect the general principle of centralization, that is to say, the gains that can be effected by diversity factor and increased output more than offset the cost due to transmission mains over wide distances. Broadly speaking, generating on a large scale means less cost of plant per kilowatt, less labour, less maintenance, less fuel consumption and greater number of hours employment of plant throughout the year. Further, the amount of capital that can be justified for economy in fuel consumption directly depends on the cost of the fuel per kilowatt per annum which, with a given cost of fuel is directly determined by the load factor. As an example of what can be effected by centralization and what is to be avoided in the economic development of electric supply for a great city, I quote the instance of London, with which I am specially familiar.

Politically there are two kinds of supply, one by the local authorities parcelled out according to the boundaries of the different parishes, the other what may be termed the Companies' area which was parcelled out by Parliament in the belief that it would be injudicious to entrust the electrical supply of more than a certain portion to a given private undertaking. As a result, the generation is at present carried out by some forty-five separate undertakings at a great variety of voltages and frequencies so that general interconnection is impracticable. Excluding railway supply, which is not here considered, the energy consumption amounts to 400 million kilowatt hours per annum. Generally speaking, none of the stations possess proper facilities for generation on a large scale. Very many of the stations are located on costly sites, so that the site value of the existing undertakings would go a long way towards creating a general bulk supply. The sum of the individual maximum loads amounts to 217,500 K.W. per annum or an average load factor taken over the whole of 21%. The generating cost amounts to £1,080,000 per annum. This could be replaced by a bulk supply undertaking properly located as regards coal, condensing and all other conditions favourable to a bulk supply with an average distance of transmission of 10

miles. Allowing for such losses as would have to occur provided the present kinds of supply were continued in each place the average efficiency of distribution would be 75%. If standardized so that the distribution be done generally at 50 cycles, which is the most economical way of attending to a general supply, the efficiency would be 85%. The general diversity amongst these various undertakings if concentrated would approximate to 1.35, which would of course improve with the increased power load that would follow upon concentration and a cheap supply. This diversity would bring the general load factor up to 28.5 equivalent to a maximum station load of 214,000 K.W. Assuming two stations each of 125,000 K.W. installed capacity, the cost of generation would be 0.185 pence per kilowatt hour (See Fig. 4). The total cost of generating 535 million units corresponding to 75% efficiency or 472 million units corresponding to 85% efficiency would not exceed £412,000 per annum at 75% or £364,000 at 85%, representing a saving of over £625,000 or £675,000 respectively, after allowing for maintenance of the mains. The cost of the generating stations would be £3,000,000 and the cost of the transmission system £1,284,000, making a total of £4,284,000, so that the economy effected by centralizing the supply would amount to 14.6% on the capital cost in the first case and 15.7% in the second.

The cost of this bulk supply installation including mains would be £17 per kilowatt, whereas the cost of the existing stations exceeds £50 per kilowatt.

The existing installations consume about one million tons of coal per annum, whereas the bulk supply station would not consume more than 450,000 tons of the same class of fuel. It will thus be seen that, independent of those economies that can be effected by concentrating the forty-five undertakings into one, the capital required for generation in a proper bulk supply would be 35% and the fuel cost 45% of the amount obtaining under the existing arrangement.

The case of London is best known on account of its magnitude and shows the extent of the economic waste that may arise from decentralization of electric generation. By comparing the actual results obtained on such a large scale with the results

that would be reached by applying the data set down in the paper, a somewhat startling conclusion is reached as to the extent of the waste.

The writer is aware that different engineers may have divergent views as regards percentage variation that may arise in connection with the use of the various kinds of plant. The general purposes of the paper will be served, however, in demonstrating the broad principle that ultimate economy in fuel consumption can only be obtained by concentration.

DISCUSSION

Mr. Rushmore.

Mr. D. B. Rushmore,* Mem. A. I. E. E., pointed out that in the design of power stations, certain general fundamentals of manufacturing-plant design hold, for the design of a power station is really the design of a plant for manufacturing electricity. Among the general considerations affecting such design may be uncertainty as to future conditions, and of course all good plans are subject to readjustment for cases where conditions are only partly known. For example, rapid improvement in apparatus must always be provided for. A station laid out for certain sized units may need to use double that size unit.

Power-station design for normal conditions will always be insufficient and adjustment must be provided to meet emergency conditions. Accidents may happen—any factor may fail. General independence of action must be provided for, especially in the operation of auxiliaries, as this leads to safety in operation.

Efficiency in much of the apparatus employed is now reaching a limit. The principal fields for making savings are now the boiler-house, and the transmission and distribution systems.

Mr. Weymouth.

Mr. C. R. Weymouth,† Mem. Am Soc. M. E., pointed out that on the Pacific Coast the latest trend is toward the use of very high steam pressures and superheats. Design is now for 250 to 300 or 350 lbs. pressure and 200 degrees superheat. The upper limit to superheat is reached when the use of separately-fired superheaters becomes necessary. Design should be for high pressures, as they may later be necessary, since it is difficult to predict the extremities to which conditions may be forced by future state regulation.

The steam turbine is tempting as a drive for auxiliaries. It is, however, of limited application in small plants, since turbines are not yet economically designed in small sizes. The auxiliaries are wasteful of exhaust steam. In small plants, the feed-water cannot absorb all the exhaust steam, and the percentage of lost auxiliary steam increases as the load decreases. The lighter loads must be remembered, since there

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is then greater relative waste of exhaust steam. In this connection, a noteworthy case is the power-plant for the city of Seattle, in which all the auxiliaries are turbine driven. The size of main unit is 7500 kw. A waste of exhaust steam exists here in the auxiliary drives at full load and exists increasingly at light loads. However, large stations may profitably use such auxiliaries. Mr. Weymouth.

Mr. H. H. Barnes, Jr.,* Mem. A. I. E. E., referring to the question of boiler pressure, observed that 175 to 200 lbs. was considered standard for a long time. Today, there is a strong desire to go higher, but pressures much higher have not yet been tried out on a large scale, although studies by H. G. Stott are now in progress. The question of added capacity in power stations is now acute in New York City. Mr. Stott is considering pressures up to 1000 lbs. (theoretically at least) with 30,000 to 40,000 kw. units. He believed that much higher pressures than 200 to 250 lbs. will be found feasible and economical, but also that they will probably be considerably lower than 1000 lbs. Mr. Barnes.

Mr. W. J. Davis, Jr.,† Mem. A. I. E. E., expressed the opinion that thorough study of the points involved in this paper may cause a revolution in the design of power stations. The present Rankine cycle efficiency for the steam turbine is 80%, which is as high as can be obtained with present vacuums and superheats. The operating vacuum where cold water is available reaches 29½ inches. He felt that engineers must look to the boiler room for further increase in economy. Mr. Davis.

By increasing the steam pressures, however, we make the design of turbine and auxiliaries more difficult. The number of blades and stages will be greatly increased. A different drive of auxiliaries must ultimately be used. Therefore, it is preferable to install a turbo-generator set to supply current for driving the auxiliaries, using electric drive for the latter.

Mr. R. R. Tschentscher,‡ Mem. A. I. E. E., pointed out that most papers on this subject have been from the view-point of central utilities. Now it is becoming true that large industrial establishments must be particularly considered. In such works, the generation of power is a side issue because their prime function is the manufacture of something else than electricity. Ideals are correspondingly different. Mr. Tschentscher.

In industrial power stations, the question of auxiliary prime movers must be investigated. Experience shows that the operating force goes to pieces when trouble occurs in high-speed revolving units. Their behavior when reciprocating units get into trouble affords striking contrast. Slow-speed reciprocating units may be operated when some part gets slightly out of order. In municipal plants, a 3- to 7-hour peak load gives a chance for inspection; but, in the steel industry, the load is rather uniform for 24 hours, since the lighting load at night replaces the ore-unloading load of the daytime.

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Paper No. 134

THE ELECTRIC MOTOR AS AN ECONOMIC FACTOR IN INDUSTRIAL LIFE.

By

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INTRODUCTION.

The electric motor as an economic factor can be truly seen only by viewing its proper place as a factor in modern industry, and in seeing modern industry as a part of the present-day activities and as the culmination of an historical growth.

The "dawn of history" may be said to have occurred with the development of articulate speech. Since then the progress of civilization has been accompanied by or has been the result of a number of distinct developments and inventions, amongst which are fire, the bow and arrow, pottery, the domestication of animals, the use of iron, the development of a written language, gun powder, the mariner's compass, paper and the printing press, the steam engine, spinning and weaving, the telegraph and telephone, and the inventions and developments too numerous for separate mention involved in our great activities of communication, transportation and manufacture.

In the development of a country, human activities progress along the line of exploration, hunting and fishing, mining, lumbering, agriculture and manufacturing.

THE AGE OF POWER.

The general peaceful activities of human beings are in connection with the transformation of raw materials into the form of finished products suitable for ultimate consumption. This process of transforming raw materials is broadly known as manufacturing, and, taken in its widest sense, includes agri-

culture, in which the raw materials may be considered as seed, soil, fertilizer, moisture, light and heat.

In general, the real raw materials are relatively few in number, and, besides, those of agriculture are obtained from the deposits of natural resources. A relatively small amount of this is consumed in its original form, and the higher the development of civilization, the more extended becomes the process of transformation of these natural forms into a condition suitable for ultimate consumption.

From the elemental raw material to the final finished product, manufacturing processes stand in series like the bucket passers of the old fire brigade. The finished product of one process or industry becomes the raw material for the next. Energy is consumed at many points, both in transforming the material and also in the local transportation, and it is this which has made the period since the beginning of the last century distinctively an age of power.

Natural products in the shape of raw material being found in different parts of the earth, and consumption of these in many cases being approximately world-wide, there is associated with the processes concerned in transforming the raw material the great activity of transportation and distribution, in which the flow and transformation of commodities may be very well likened to the transmission and distribution of electric energy in a hydro-electric power system, the manufacturing processes corresponding to the transformation in the energy at the different sub-stations and distributing points.

The power of a man working at his greatest physical capacity may be taken as approximately one eighth of a horsepower, the horsepower itself being not the average output of a horse but the maximum output of a horse of unusual strength, and then only for a comparatively short period.

The present industrial age has grouped men very largely in cities, and in the ordinary daily life of man there is consumed in connection with each individual an amount of energy much larger than that represented by the muscular activity of this person. In the preparation of our food; in the heating and lighting of our homes; in the transportation systems, by railway, trolley and elevator; and in the power consumed in con-

nection with our daily work, there is an expenditure of energy beyond the daily output of a man, and on this, to a large extent, rests the condition of civilization which we have today.

Thus we find the present highly developed civilization dependent upon the utilization of the stored energy in our natural resources or upon the energy from the sun, either directly or through water powers; and the utilization of this energy on a broad scale has been economically possible only by the use of electricity.

ADVANTAGES OF THE ELECTRIC MOTOR DRIVE.

Electricity is the most convenient form in which to transmit and apply energy, and the electric motor is a means for transforming electrical to mechanical energy, and produces motion and torque at various speeds and in different directions. The advantages of the electric drive of machinery in general are:

An increased production for a given equipment, and an improved product.

A decreased power consumption and higher efficiency.

This is due to:

Centralized power supply.

Simplicity of power transmission and distribution.

Machinery may be conveniently located with reference to production rather than to the power transmitting system.

Changes can easily be made.

Reduced friction losses and, thus, increased efficiency.

Cleanliness and better light, due to absence of a large number of belts.

Less danger of accidents.

Better reliability of operation.

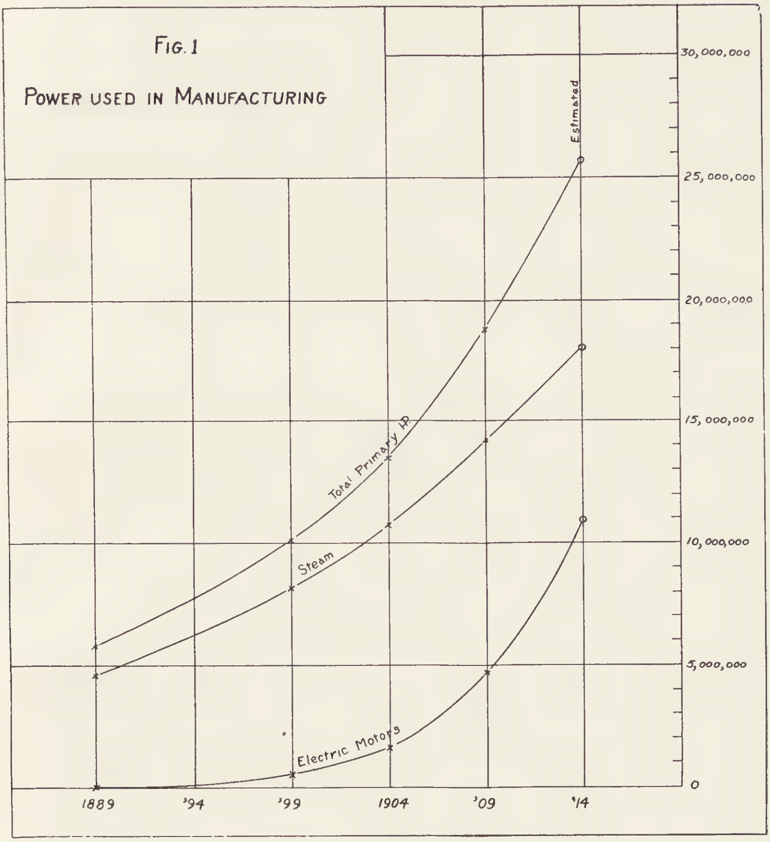
Wide choice of motors as to size, mechanical design and operating characteristics.

Perfect control, including readiness of starting and stopping and making close speed adjustments.

Remote and automatic control.

The operations may be closely studied by means of recording devices, and tests can readily be made.

Economy in time.



Ability to operate any portion of a factory at any time with a power consumption approximately proportional to the work done.

STATISTICAL DATA.

In order to show the rapid increase in the use of electric power in our industries, Tables I to VII, based on Census Reports, have been prepared.

Table I gives a summary of the manufacturing industry, including the number of establishments, number of persons engaged in the industry and its various branches, the amount of primary power used, capital, salaries, wages, cost of materials, value of products and the value added by the manufacturing process. There are no figures available later than the 1909

Census Report, but an endeavor has been made to approximately estimate the amount of primary power used in the manufacturing industry at the present time and also the total horsepower value of the electric motors used therein. These results are plotted in the curves, Fig. No. 1, and it may be safely assumed that the amount of primary power used is very close to twenty-five million horsepower and that electric motors of a combined capacity of approximately ten or eleven million horsepower are in use in the manufacturing industry alone.

Table II gives the horsepower capacity of electric motors used in some of the leading manufacturing industries, as well as the whole industry for the years 1899-1904-1909. The horsepower required per $1000 value of product and per person engaged in the industries is given in Table III.

Table IV gives the amount of primary power and electric motors used in the mining industry, while Table V gives some statistical data in regard to street and electric railways and shows how completely the old methods of drive have been superseded by the electric-motor drive.

Table VI gives the number of central stations in the country, their primary power and generator capacities. It also contains figures as to the number and horsepower of stationary motors served, and the rapid increase in this field clearly illustrates the advantages of purchasing central-station power.

TABLE II.

Electric Motors in Leading Manufacturing Industries.

	Horsepower		
	1909	1904	1899
Agricultural Implements	38,905	20,713	7,643
Automobiles	41,829	4,229	
Car and Railroad Repair Shops	161,288	52,635	4,563
Cement	158,749	35,292	
Cotton Goods	235,902	67,139	17,594
Electrical Machinery	164,540	61,753	24,256
Foundry and Machine Shops	623,914	199,625	54,907
Iron and Steel—Blast Furnaces	135,143	52,610	8,693
Iron and Steel—Rolling Mills	716,609	254,258	64,658
Lumber and Timber Products	130,707	33,517	11,315
Paper and Wood Pulp	130,120	31,604	2,814
Printing and Publishing	229,312	93,219	41,413
Total	4,817,140	1,592,475	492,936

TABLE I

SUMMARY OF MANUFACTURES

INDUSTRY	Census Year	No. of Establishments	Persons Engaged in Industry				Primary Horse Power	Capital	Salaries	Wages	Cost of Materials	Value of Products	Val. added by manuf're (Val. of Products less cost of Materials)
			Proprietors & Firm Members	Salaried Employees	Wage Earners (Average Number)	Total		Expressed in Thousands of Dollars					
Agricultural Implements	1909	640	465	9,213	50,551	60,229	100,601	256,281	10,140	28,609	60,307	146,329	86,022
	1904	645	496	7,199	47,394	55,089	89,738	196,741	7,573	25,003	48,281	112,007	63,726
	1899	715		10,046	46,582		70,646	157,708	8,363	22,541	43,945	101,207	57,262
Automobiles, including bodies and parts	1909	743	405	9,233	75,721	85,359	75,550	173,837	9,479	48,694	131,646	249,202	117,556
	1904	178	103	1,181	12,049	13,333	10,109	23,084	1,257	7,159	13,151	30,034	16,883
	1899	57		[illegible]	2,241			5,769	295	1,321	1,804	4,748	2,944
Boots and Shoes, including cut stock and findings	1909	1,918	1,838	15,788	198,297	215,923	96,302	222,324	18,629	98,463	332,738	512,798	180,060
	1905	1,895	2,128	9,518	160,294	171,940	63,968	136,802	9,412	73,072	225,288	357,688	132,400
	1899	2,253		8,348	151,231		55,489	110,363	8,159	61,924	191,456	290,047	98,591
Boots and Shoes, Rubber	1909	22		1,287	17,612	18,899	25,903	43,905	1,415	8,544	29,577	49,721	20,144
	1904	22	2	822	18,991	19,815	26,084	39,412	874	8,867	32,000	70,065	38,065
	1899	22		483	14,391		25,017	33,668	597	6,427	22,683	41,090	18,407
Brass and Bronze Products	1909	1,021	538	3,395	40,618	45,441	106,120	109,319	5,540	23,677	99,228	149,989	50,761
	1904	813	784	3,000	33,168	36,952	69,494	77,438	7,778	17,666	65,653	102,407	36,754
	1899	695		1,813	27,166		47,257	51,120	2,297	13,599	61,189	88,654	27,465
Bread and other Bakery Products	1909	23,926	26,982	17,124	100,216	144,322	65,298	212,910	13,764	59,351	238,034	396,865	158,831
	1904	18,226	20,037	8,358	81,278	109,673	37,241	122,353	6,273	43,172	155,989	269,583	113,594
	1899	14,836		9,167	60,192		22,472	80,902	6,063	27,864	95,052	175,369	80,317
Brick and Tile	1909	4,215	4,285	4,951	76,528	85,764	341,169	174,673	5,439	37,139	23,736	92,776	69,040
	1904	4,634	5,295	3,690	66,021	75,006	255,352	119,957	3,530	28,646	16,317	71,152	54,835
	1899	5,423		2,426	61,979		176,700	82,086	2,025	21,883	11,006	51,270	40,264
Cars and General Shop Construction and Repairs by Steam-Railroad Companies	1909	1,145	2	19,097	282,174	301,273	293,361	238,317	17,339	181,344	199,413	405,601	206,188
	1904	1,140		13,329	236,870	250,199	167,973	146,886	11,920	142,153	151,105	309,775	158,670
	1899	1,292		7,094	173,595		95,087	119,473	6,208	96,007	109,472	218,114	108,642
Cement	1909	135	17	2,719	26,775	29,511	371,799	187,398	3,653	15,320	29,344	63,205	33,861
	1904	129	26	1,383	17,478	18,887	149,604	85,759	1,858	8,814	12,215	29,873	17,658
Chemicals	1909	349	154	3,923	23,714	27,791	208,604	155,144	6,137	14,085	64,122	117,689	53,567
	1904	275	123	2,778	19,806	22,707	132,262	96,621	4,048	10,790	42,063	75,222	33,159
	1899	433		2,123	19,020		90,349	89,069	2,923	9,393	34,546	62,637	28,091
Copper, Tin, and Sheet-iron Products	1909	4,228	4,423	8,896	73,615	86,934	62,366	217,532	10,288	39,501	112,582	199,824	87,242
	1904	2,540	2,851	4,827	53,035	60,713	30,229	147,608	6,080	26,269	63,921	119,933	56,012
	1899	1,985		2,924	38,317		28,829	49,679	2,810	16,924	42,602	78,359	35,757
Cotton Goods, including Cotton small wares	1909	1,324	377	8,514	378,880	387,771	1,296,517	822,238	14,412	132,859	371,009	628,392	257,382
	1904	1,154	432	6,981	315,874	323,287	986,604	613,111	10,238	96,206	286,255	450,468	164,213
	1899	1,055		4,902	302,861		795,834	467,240	7,350	86,690	176,552	339,200	162,648
Electrical Machinery, Apparatus, and Supplies	1909	1,009	439	17,905	87,256	105,600	158,768	267,844	20,193	49,381	108,566	221,309	112,743
	1904	784	400	10,619	60,466	71,485	105,376	174,066	11,091	31,842	66,837	140,809	73,972
	1899	581		5,067	42,013		43,674	83,660	4,632	20,579	49,458	92,434	42,976
Fertilizers	1909	550	323	3,317	18,310	21,950	64,711	121,537	4,406	7,477	69,522	103,960	34,438
	1904	399	294	1,613	14,184	16,091	47,989	68,917	1,934	5,127	39,288	56,541	17,253
	1899	422		1,712	11,581		38,680	60,686	2,125	4,185	28,958	44,657	15,699
Flour-mill and Grist-mill Products	1909	11,691	14,570	12,031	39,453	66,054	853,584	349,152	12,517	21,464	767,576	883,584	116,008
	1904	10,051	13,098	7,415	39,110	59,623	775,318	265,117	7,352	19,822	619,971	713,033	93,062
	1899	9,476		5,522	32,226		670,719	189,281	5,258	16,285	428,117	501,396	73,279
Foundry and Machine Shop Products	1909	13,253	9,851	74,623	531,011	615,485	869,305	1,514,332	93,795	321,521	540,011	1,228,475	688,464
	1904	10,765	9,370	49,406	443,409	502,185	606,165	1,034,135	59,703	246,573	367,412	880,514	513,102
	1899	11,046		34,286	426,985		443,085	790,741	39,318	219,870	363,036	798,454	435,418
Ice, Manufactured	1909	2,004	1,066	3,927	16,114	21,107	317,789	118,641	3,868	9,779	11,317	42,953	31,636
	1904	1,320	746	2,332	10,101	13,179	191,660	66,592	2,001	5,549	6,011	23,790	17,779
	1899	775		1,531	6,880		100,421	38,020	1,226	3,403	3,312	13,781	10,469
Iron and Steel, Blast Furnaces	1909	208	46	4,584	38,429	43,061	1,173,422	487,581	6,525	24,607	320,638	391,429	70,791
	1904	190	26	2,231	35,078	37,335	773,278	236,146	2,891	18,935	178,942	231,823	52,881
	1899	223		1,757	39,241		497,272	143,159	2,304	18,484	131,504	206,757	75,253
Iron and Steel, Steel Works and Rolling Mills	1909	446	47	20,639	240,076	260,742	2,100,978	1,004,735	26,191	163,201	657,501	985,723	328,222
	1904	415	64	14,330	207,562	221,956	1,649,299	700,182	17,860	122,492	441,204	673,965	232,761
	1899	445		7,454	183,249		1,100,801	430,232	9,433	102,336	390,895	597,212	206,317
Leather, Tanned, Curried and Finished	1909	919	784	4,114	62,202	67,100	148,140	332,727	6,744	32,103	248,279	327,874	79,595
	1904	1,049	1,112	3,251	57,239	61,602	117,450	242,584	4,452	27,049	191,179	252,621	61,442
	1899	1,306		2,442	52,109		88,860	173,977	3,159	22,591	155,000	204,038	49,038
Lumber and Timber Products	1909	40,671	48,825	41,145	695,019	784,989	2,840,082	1,176,675	47,428	318,739	508,118	1,156,129	648,011
	1904	25,153	30,738	30,038	532,566	593,342	1,886,624	733,708	31,737	245,834	360,325	884,267	523,942
	1899	28,133		20,940	508,766		1,658,594	541,595	18,715	188,395	364,964	760,902	396,028
Paper and Wood Pulp	1909	777	250	5,245	75,978	81,473	1,304,265	409,348	9,510	40,805	165,442	267,657	102,215
	1904	761	309	3,778	65,964	70,051	1,093,708	277,444	6,097	32,019	111,252	188,715	77,463
	1899	763		2,935	49,646		752,118	167,508	4,501	20,746	70,530	127,326	56,796
Printing and Publishing	1909	31,445	30,424	99,608	258,434	388,466	297,763	588,346	103,458	164,628	201,775	737,876	536,101
	1904	27,793	28,368	68,592	219,087	316,047	166,380	432,854	67,748	127,196	142,514	552,473	409,959
	1899	23,814		40,685	195,260		119,775	333,003	39,475	99,816	103,654	395,187	291,533
Slaughtering and Meat-packing	1909	1,641	1,659	17,329	89,728	108,716	208,707	383,249	20,054	51,645	1,202,828	1,370,568	167,740
	1904	1,221	1,324	12,096	75,399	88,819	119,311	240,419	13,453	41,067	811,426	922,038	110,612
	1899	1,080		10,317	69,264		87,060	190,209	10,211	33,846	685,310	788,368	103,058
Smelting and Refining, Copper	1909	38	7	1,197	15,628	16,832	158,126	111,443	2,419	13,396	333,532	378,806	45,274
	1904	40	1	[illegible]	12,752	13,562	76,524	76,825	1,527	10,827	196,737	240,780	44,043
	1899	47		488	11,324		61,630	53,063	955	8,529	122,174	165,132	42,958
Woolen, Worsted and Felt Goods, and Wool Hats	1909	985	732	5,722	168,722	175,176	362,209	430,579	10,097	72,427	282,878	435,979	153,101
	1904	1,074	958	4,593	146,755	152,306	288,969	314,081	6,781	57,073	204,613	319,348	114,735
	1899	1,281		3,808	130,697		244,825	265,730	5,574	46,812	153,930	248,798	94,868
Total all Industries	1909	268,491	273,265	790,267	6,615,046	7,678,578	18,675,376	18,428,270	938,575	3,427,038	12,142,791	20,672,052	8,529,261
	1904	216,180	225,673	519,556	5,468,383	6,213,612	13,487,707	12,675,581	514,439	2,610,445	8,500,208	14,793,903	6,293,695
	1899	207,514		364,120	4,712,763		10,097,893	8,975,256	380,771	2,008,361	6,575,851	11,406,927	4,831,076

TABLE III.

Power Required for Manufacturing Based on 1909 U. S. Census.

	Horsepower Required per $1000 Production	Horsepower Used per Person Engaged in Industry
Agricultural Implements	0.69	1.67
Automobiles	0.30	0.89
Boots and Shoes	0.19	0.45
Brick and Tile	3.68	4.00
Cement	5.90	12.60
Chemicals	1.78	7.50
Copper, Tin and Sheet-Iron Products	0.31	0.72
Cotton Goods	2.07	3.35
Electrical Machinery	0.72	1.50
Fertilizers	0.62	2.95
Flour and Grist-Mill Products	0.97	12.90
Foundry and Machine Shops	0.71	1.41
Manufactured Ice	7.40	15.05
Iron and Steel—Blast Furnaces	3.00	27.30
Iron and Steel—Rolling Mills	2.13	8.06
Leather—Tanned, Curried and Finished	0.45	2.21
Lumber and Timber	2.46	3.62
Paper and Wood Pulp	4.88	16.05
Printing and Publishing	0.40	0.77
Packing Houses	0.15	1.92
Copper Smelting and Refining	0.42	9.41
Woolen, Worsted and Felt Goods	0.83	2.06
Total—All Industries 1909	0.91	2.45
1904	0.91	2.17

TABLE IV.

Power Used in Mining.

	1909 Hp.	1902 Hp.
Primary Power		
Total	4,699,910	2,867,562
Steam Power	3,840,923	2,432,963
Electric Motors	723,727	
Horsepower required per $1000 value of product	3.82	3.6
Horsepower used per person engaged in industry	4.00	4.62

TABLE V.

Street and Electric Railways.

	1912 Hp.	1907 Hp.
Primary Power		
Total	3,665,051	2,519,823
Steam Power	3,169,554	2,368,183
Miles of Track Operated by		
Electricity	40,808	34,037
Cable	56	61
Animal Power	57	136
Steam	76	105
Gasolene	66	40
Number of Cars Equipped with		
Electric motors	73,758	63,504
One motor	1,207	629
Two motors	45,996	45,660
Three motors	749	422
Four or more motors	25,806	16,793

TABLE VI.

Commercial and Municipal Central Stations.

	1912	1907	1902
Number of Stations	5,221	4,714	3,620
Primary Horsepower			
Total	7,528,648	4,098,188	1,845,048
Steam	4,946,532	2,693,273	1,394,395
Water	2,471,081	1,349,087	438,472
Gas	111,035	55,828	12,181
Kw. Capacity of Dynamos	5,134,689	2,709,225	1,212,235
Stationary Electric Motors Served			
Total Number	435,473	187,652	111,113
Total Horsepower	4,130,619	1,807,949	473,693
Average Number per Station	83	35	28
Average Horsepower per Station	791	350	121
Average Horsepower per Motor	9.5	9.9	4.3

CLASSIFICATION OF MOTORS, AND FACTORS INVOLVED IN THEIR APPLICATION.

Lacking standardization at the beginning entails the necessity for manufacturing varieties necessitated only by the con-

ditions of existing systems and not by the intrinsic natural requirements. In the past, the electric motor has been adapted to the machine to be driven, but seldom is the reverse true, that the machine is adapted to the motor. While much work has been done towards a standardization of motor sizes, speeds, voltages and mechanical details, it is astonishing to note the thousands of varieties of motors which are being specified, and for which, of course, a large amount of special parts must be kept in stock by the manufacturers to meet reasonable deliveries; not to speak of the increased cost of the product.

The variety of electric-motor designs, from the standpoint of a large electric manufacturing company, is thus seen in the following general classification.

Current.

This may be direct or alternating current, but the advantages of the latter are, as a rule, so many that it is almost always selected for industrial plants. If direct-current motors are required for a variable-speed service, motor-generator sets can readily be provided for the conversion.

Phases.

These may be:

Single-phase.

Two-phase, three- or four-wire.

Three-phase, three- or four-wire, with grounded or ungrounded neutral.

Six-phase.

Frequencies.

The following list gives the different frequencies for which motors have been designed: 15, 25, 30, 33, 40, 42, 50, 60, 62½, 66, 125, 133, 300. This latter frequency, 300, was used for a ball-bearing grinding motor operating at a speed of 18,000 r.p.m.

While 40 cycles might possibly have been the best frequency for general use, it did not become standard, and the choice is now between 25 and 60. The former has been used extensively for power work, but there is every indication that 60 cycles is gaining rapidly in favor, even for this class of service. One of its advantages is the greater number of motor speeds which is possible, as compared with the lower frequency.

Voltages.

In motor design, over fifty special voltages are met with, distributed between 6 and 16,000.

For direct-current industrial motors, 115 and 230 volts have been adopted standard voltages. For small alternating-current motors, 110 and 220 volts are standard, while for larger sizes, 440, 550 and 2200 volts have been adopted. In certain large installations, 6600 volts are also used, the particular voltage to be selected being mainly governed by the most economical distributing pressure.

Capacities.

It is almost impossible to tabulate all the different motor capacities which have been built or for which designs have been made. So, for example, are fractional horsepower motors built in not less than sixteen different sizes varying from 1/200 hp. to ¾ hp. There are forty-four different sizes between 1 and 100 horsepower and twenty-three sizes between 100 and 1000 horsepower. Direct-current motors have been built in sizes up to 2000 horsepower, and alternating-current motors are, at the present time, being built in sizes up to 7500 horsepower, while sizes over twenty thousand horsepower have been considered for the propulsion of ocean liners.

Speeds.

The speed of synchronous motors is fixed by the frequency of the supply circuit and the number of poles of the machine, the relation being expressed by the equation:

$$\text{Revolutions per Minute} = \frac{\text{Cycles x 120}}{\text{Number of Poles}}$$

For induction motors, however, this condition does not hold true under load, as the speed then falls off somewhat, the percentage of decrease below synchronous speed being called the "slip". This slip of an induction motor, over the usual ranges of operation, varies directly with the load and the rotor resistance, and inversely as the square of the applied voltage.

There are hundreds of different speeds for which motors have been built—alternating-current motors from as low as 55 r.p.m. to as high as 18,000, and direct-current motors from 53.5 to 3450 revolutions per minute.

Speed Classification.

Motors may, for convenience, be classified with reference to their speed characteristics as follows:

Constant Speed—Where the speed is constant or varies only slightly.

Adjustable Speed—Where the speed may be varied over a considerable range, but when once fixed, remains at this value, independent of the load changes.

Varying Speed—Where the speed changes with the load, usually decreasing as the load increases.

Multi-Speed—Where several distinct speeds may be obtained by changing the connections of the windings or by other means.

Classification According to Current.

- Direct Current
    - Series
    - Shunt
    - Compound
    - Differential
- Alternating Current
    - Synchronous
    - Induction
        - Phase-wound
        - Squirrel-cage
    - Synchronous-Induction
    - Commutator
        - Series-Characteristics
        - Shunt-Characteristics
        - Compound-Characteristics

Classification According to Operating Characteristics.

Series Motors: The torque increases faster than the current and is a maximum at minimum speed. The speed varies with the load, being high at light load and low at heavy load. The efficiency is high throughout a wide range of speed as well as load.

Shunt Motors: The torque is directly proportional to the armature current, irrespective of speed. Approximately constant speed for all reasonable variations of load. Efficiency

high throughout a wide range of load, but only for a small range of speed.

Compound Motors: Combine the characteristics of series and shunt motors, having a powerful starting torque and an increasing torque with decreasing load. Speed not extremely variable under load changes, thus avoiding the danger of excessive speed at light loads.

Differential Motors: The series and shunt windings oppose each other, and these motors have, therefore, poor starting qualities. Speed increases with increase of load, but they have no tendency to run at dangerously high speed. Used only rarely for special applications.

Synchronous Motors: The speed of a synchronous motor is constant, being fixed by the number of poles and the frequency of the applied voltage. The single-phase type is not self-starting and requires some auxiliary motor to bring it up to synchronous speed and into proper phase relation before it can be properly connected to the supply circuit. The polyphase type has a limited starting torque, unless special features are added to assist its inherent starting characteristics. They are, therefore, usually provided with amortisseur starting windings; and the starting torque, due to the currents in this winding, is proportional to the square of the current induced and to the resistance of the winding. A motor of large armature reaction and high-resistance starting winding will have a high starting torque. The amount of load that the motor will bring up to synchronism and pull in depends, also, on the starting winding; but, in this respect, a low resistance amortisseur winding is required to get the best results or the least slip, and from this standpoint, high synchronizing torque is antagonistic to high starting torque, and vice versa. This factor is, however, not an especially difficult one to meet if the requirements are known beforehand, as it is seldom that the same motor will be called upon to start a heavy load and, at the same time, synchronize a heavy load.

The phase characteristics of a synchronous motor are of importance, as they show the variation in armature current for any given load with varying field excitation, and there is a certain field current at each load that causes a minimum cur-

rent to flow. Any increase or decrease of field from this value increases the current and causes it to lead or lag in phase with respect to the line voltage.

Induction Motors, Phase-Wound: High starting torque with moderate starting current. Constant- or variable-speed service, the latter being obtained by means of an adjustable resistance in the rotor circuit.

Induction Motors, Squirrel Cage: Constant-speed service with infrequent starting. Relatively small starting torque per ampere. By increasing the rotor resistance, thus decreasing the efficiency, it may, however, be built for high starting torque. Chief advantages are simplicity and durability.

Synchronous-Induction Motors: The same general construction as the wound rotor induction motor, the synchronous operation being obtained by exciting with low-voltage direct current across one phase of the rotor winding. Better starting characteristics than the synchronous motor. The operation of the latter is, however, more stable under varying loads and fluctuating voltage, while it may be economically designed for power factor improvements. Its cost is also lower.

A. C. Commutator Motors: The characteristics of these motors are such that with suitable control they can be used in place of corresponding types of direct-current motors.

Consideration of the factors involved in a motor application necessitates a careful study, not only of the conditions under which the motor is to operate, but also the characteristics of the motor itself.

Load Conditions.

A complete knowledge of the load condition is, of course, absolutely essential for the selection of a satisfactory motor equipment. It is best represented by a load diagram for a complete cycle of operation, and the frequency with which these cycles are repeated must also be given.

The manufacturing process and the load diagram should be carefully studied to ascertain if any part of the cycle can be varied with benefit. Arrangements may also be made so that intermittently-operated machines need not be operated simultaneously, thus giving a smoother load curve and allowing the use of a smaller motor to drive several intermittent

machines. Future conditions, such as an increase in the output and load, must be given consideration—also possible variations in the load caused by change of conditions, such as a decrease in head on a centrifugal pump, etc. Allowance must then be made in the motor size to take care of such contingencies.

The starting conditions should also be carefully studied. Even though the size of the motor may be sufficient for normal running, it may not be able to develop enough torque at starting, or the starting current may be excessive.

A study of the starting conditions involves the torque, horsepower and time of acceleration. In many applications the "breaking away torque" is considerably higher than the running or accelerating torque, while in others the conditions may be such that the load increases as the motor comes up to speed.

Motor Rating and Limitations.

There are various kinds of motor ratings, such as:

1. Continuous duty, where the load is practically constant over long periods of time.
2. Short-Time Rating:
   a. Cycle duty, in which a definite cycle repeats itself with more or less regularity, the machine stopping between each cycle.
   b. Varying-load duty, in which more or less definite cycles are repeated, but the motor runs continuously.

Among the limitations in the rating of motors, the following factors enter:

Mechanical strength.
Insulation strength.
Heating.
Commutation.
Regulation.
Efficiency.
Power factor (A. C.).
Output.
Torque (starting and maximum).

Mechanical Design.

The operating as well as local conditions have a great bear-

ing on the mechanical features of a motor; some of these mechanical features being listed below:

Types of Motors:

Horizontal or vertical; open; protected; semi-enclosed; totally-enclosed; enclosed, externally ventilated; enclosed, self-ventilated; water cooled; moisture proof; splash or water proof; submergible; dust proof; high temperature proof; acid and alkali proof; explosion proof.

Bearings:

Types: Cylindrical, step, thrust, plate, ball, roller, pivot.

Materials: Cast iron, steel, gun metal, phosphor bronze, white alloys, lignum vitae and other hard woods.

Lubrication:

Oils—Vegetable, animal, mineral; greases; solids.

Methods of Application:

Compression grease cups; wick or siphon feed; oil pad pressed against the journal; oil rings or chains; centrifugal means; oil bath; gravity feed; forced feed.

Method of Drive:

Belt:

Various forms of leather; rubber; cast iron; wood or paper pulleys.

Gear:

Steel; cast iron; fabric.

Coupling:

Rigid; various forms of flexible.

Rope.

Chain.

Friction.

Accessories:

Bases, rails, foundation plates, number of bearings, belt tighteners, shaft extensions.

Special Types of Motors:

The numerous special features which must be met for certain industries have made it desirable to design certain lines of motors which are particularly suited for these classes of

service. Among these may be mentioned: Attrition mills, automobiles, blowers and fans, buffing and grinding, cement mills, coal cutters, compressors, cranes, dentistry, elevators, hoists, linotype machines, machine tools, oil wells, printing presses, pumps, railways, sewing machines, sugar centrifugals, textile mills, etc.

Control Equipment.

The function of a control equipment is to regulate the speed and direction of the motors and to protect the machinery and operators against abnormal conditions, this being accomplished by certain definite systematic changes in the connections.

The speed variations of direct-current motors are usually accomplished by varying the armature or field circuits, or both, if the motors run separately, or by various groupings of motors in series and parallel, where the motors are in pairs, as is usual in railway practice.

The starting of squirrel-cage induction motors may be accomplished either by connecting the motors to compensator taps or, for small motors, by inserting resistance in the primary leads. For wound-rotor motors a resistance is inserted in the secondary circuit. Speed control of alternating-current motors may be accomplished by secondary resistance, pole-changing, concatenation, brush shifting and dynamic regulation.

It is beyond the scope of this paper to discuss in detail all the numerous features entering into the selection of control equipments for the various classes of motors and service conditions, and only a brief outline of the points to be considered will be given in the following:

1. Functioning of Equipment.
   a. Personal or impersonal (automatic) pilot control.
      I. Personal control without any automatic aids or limitations.
      II. Personal control by aid of power-operated control devices, but without any automatic limits.
      III. Personal control, subject to automatic limitations of rate of change.
      IV. Personal control for a portion of the cycle and automatic control, irrespective of persons, for remainder of cycle.
      V. Complete automatic impersonal control.

b. Requirements for driven machine.
   I. To control starting, retarding or reversing with reference to load or shocks imposed on driven machinery.
   II. To control speed or torque with reference to requirements of production.
   III. To start and stop one motion with respect to a related, but separately driven, motion.

c. Requirements for motor and power circuit.
   I. Protection against injurious commutation.
   II. Limiting of mechanical shocks to motor.
   III. Limiting of momentary load on line.
   IV. Limiting of heating.
   V. Conservatism of energy required for operation.

d. Protection against abnormal conditions.
   I. Short circuits.
   II. Momentary overloads on motor, line or driven machinery.
   III. Time overloads on motor.
   IV. Over speed.
   V. Failure of voltage.
   VI. Emergency shut-down by other means—e. g., by hand from remote points; automatically, by breakage of machinery, etc.

2. Capacity.

a. Capacity of main circuit-changing parts.
   I. To close on peak loads during acceleration.
   II. To carry momentary running loads occurring after closing is completed.
   III. To open under load.
   IV. To carry sustained loads.

b. Capacity of rheostats or compensators.
   I. Heat storage and dissipating capacity for making heaviest single start or reversal, or required number of starts or reversals in rapid succession.
   II. Heat dissipating capacity to make required number of starts per hour or per day.

III. Capacity for prolonged operation at partial speed (rheostat only).

IV. Ability to withstand instantaneous load fluctuations without excessive mechanical stresses due to magnetic fields.

V. Ohms or voltage taps for limiting torque or current in-rush, as required.

3. Reliability and Convenience of Operation.
   a. Certainty of opening of circuits.
   b. Voltage range.
   c. Interlocking for invariable sequence.
   d. Interlocking to prevent short-circuits in making transitions.
   e. Adjustment for adaptation to load conditions not precisely predetermined.
4. Local Conditions.
   a. Atmospheric conditions, e. g., dust, humidity, etc.
   b. Room temperature.
   c. Stability of mounting, vibrations, etc.
   d. Safety rules.
   e. Underwriters' rules.
   f. Class of labor used. Custom of the trade regarding inspection and repairs.

The subject of the life of the equipment has not been included in the above. Where conditions are severe, the life, capacity as in (2), and the reliability as in (3) are all dependent on one another.

Economy.

In the consideration of the electric motor as an economic factor, the following points are also of interest in a comparison of the electric-motor versus other forms of drive, and afford a basis of comparison between motors of different characteristics:

The cost and value of efficiency, capacity, power factor, starting and maximum torque, torque per ampere, weight per horsepower, space per horsepower, regulation, appearance, etc.

The cost and value of reliability and of duplication insurance.

The cost of insurance against failure of any part involving the loss, by interruption, of operations.

The cost of motor and controller as percentage cost of the entire equipment.

The cost of motor in terms of value of product.

The cost of energy in percentage cost of unit of product.

The influence of electric motors on the quality and quantity of product.

Cleanliness.

Safety insurance.

FIELDS OF MOTOR APPLICATION.

Manufacture is defined by the Century Dictionary as "The operation of making goods or wares of any kind; the production of articles for use from raw or prepared materials by giving to these materials new forms, qualities, properties or combinations, whether by hand labor or machinery".

The principal industries and classes of service from the standpoint of the use of electric power are as follows:

Industries:

> Agriculture, automobile, bakeries, boiler works, bottling works, box factories, breweries, brick factories, broom factories, building construction, candy factories, carpet and rug factories, cement, clothing, corn mills, cotton mills, cotton seed oil mills, creameries, dairies, dye works, flour mills, foundries, freight handling, glass factories, glove factories, hardware manufacture, harness factories, ice machines, irrigation, knitting factories, laundries, lumber mills, machine shops, mattress and spring factories, meat packing, mining, paint works, paper box factories, paper and pulp mills, piano factories, pipe mills, planing mills, porcelain factories, railways, refrigeration, rubber industry, shoe factories, shoe repairing, soap factories, spice factories, steel mills, stone quarries, stove factories, sugar industry, tanneries, textile mills, tile factories, tobacco factories, trunk factories, wagon factories, wall paper factories, woodworking factories, woolen and worsted mills.

Classes of Service:

Air compressors, blowers, coal cutters, concrete mixers, conveyors, cranes, crushers, dental appliances, dredges, elevators, exhausters, fans, hoists, ice cream freezers, lime kilns, locks, pumps, printing presses, rock drills, sewing machines, ship propulsion, towing machinery, turntables, vacuum cleaners, vehicles, washing machines.

OUTLINE OF AN INDUSTRY.

All industries have certain common features which are of general interest. Amongst these are the following:

Description of the finished product.

Description of raw material.

Detailed description and explanation of the manufacturing process.

Description of equipment.

Power supply and energy consumption.

Labor.

Transportation of raw material, finished product, and during process of manufacture.

Location of raw material.

Location of centers for distribution and consumption of finished product.

Location of manufacturing plants.

Number of men employed in industry.

Exports and imports of raw material and finished product.

Further processes and work necessary on finished product to make it available for final consumption.

Capital invested in industry.

Gross sales.

Net profit.

Value added to raw material by process of manufacture.

Annual capital turn-over.

Output per man.

Capital invested per man.

Diagram of flow of material through factory.

Diagram of processes and items involved in cost estimate of product.

Diagram of ground floor plan of factory.

Curve of output of product over term of years.

Curve showing reduction in cost of product over term of years.

Photographs and drawings of machines utilized in process, showing location of motors and controllers.

Load curves for individual machines.

List of characteristics peculiar to each machine.

Data regarding the products and labor of each machine necessary for determining the kind and position of control.

Peculiar requirements of industry from the standpoint of the application of electric motors.

Special features required on motors, such as, for instance, those used in steel mills, mines and cement mills.

Starting requirements.

Effect of interruptions of power supply and precautions to be taken in connection therewith.

Requirements of process for speed variation and regulation.

Possibility of improvement in quality and quantity of product by use of electric motor.

Power requirements per unit of output.

Capacity of station required.

Characteristics desirable in system of electric distribution.

DISCUSSION

Mr. D. H. McDougall,* Assoc. A. I. E. E. (by letter), agreed with Mr. Rushmore that the use of motor drive to replace steam drive is on the increase and properly so, and we can safely assume, with the advances made in the adaptation of electric drive, that, except for some few special uses, it will shortly become the prevailing practice and steam drive the exception. Mr. McDougall.

In connection with Mr. Rushmore's exposition of the advantages of electric motor use, he desired to emphasize the reliability of operation as compared with small steam or gas engines; also the advantage of locating the motor with reference to convenience of production and not having to locate the production to accommodate belting and shafting. He also wished to emphasize the point made by Mr. Rushmore of increased and improved production, especially with variable-speed motor drive.

It seemed also that emphasis should be laid on Mr. Rushmore's statement that "complete knowledge of the local conditions is absolutely

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Mr. McDougall.

essential for the selection of a satisfactory motor". Equal emphasis should also be laid on the selection of proper control equipment for motor drive. Improper selection causes a large percentage of motor trouble, thus retarding the almost universal use of electric drive.

Mr. Rushmore states as one of the advantages of motor drive—"less danger from accidents". The writer wished to emphasize, in this respect, the value of central-station service, with particular stress on the elimination of accidents from fly-wheels and boilers.

In conclusion, he desired to add, on behalf of the central station, that the facilities afforded consumers by central-station distribution and the development of the electric motor, have resulted in the tremendous increase in small manufacturing establishments.

Paper No. 135

THE INFLUENCE OF THE ELECTRIC MOTOR ON MACHINE TOOLS.

By

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Though the changes in machine tools since the application of the electric motor are quite marked, it is often difficult to trace the effect of the electric motor on the design of the machine tool. This is mainly so, because high-speed steels were introduced, practically speaking, simultaneously with the electric motor. The two causes may appear completely different, yet their effects have been much the same.

The introduction of high-speed steel called for greater speed, more power, and better control. The electric motor afforded the means to meet these requirements and it will be found that it was quite as often the case that heavier cuts were taken because more power was available, as that more power was provided because heavier cuts had to be taken. There will, therefore, always be room for a difference of opinion as to whether certain changes in machine tools are the result of the introduction of the electric motor, or of the introduction of high-speed steel. In the following pages, the writer can do no more than give his personal opinion on these matters, basing his opinion on a number of years of close observation and close contact with the problem.

The main advantage of the application of an electric motor to a machine tool was, at first, believed to be the possibility of having individual drive for a machine and thus making it possible to place it anywhere in the shop, regardless of the location of other machines, or of the line shaft or other transmission machinery. This was especially an advantage in shops for large work, where the handling of a piece of work was as much of a

problem as the actual machining. One of the main reasons why the majority of shops for large work were made of the lantern type was that this construction allowed of a high bay in the center, in which a traveling crane could be operated, and low bays on the sides, where counter-shafts could be located. It was possible, in this way, to have planers and boring mills with their drive under the low bay and their tables under the high roof, and thus serve them from the traveling crane without much trouble. Lathes and similar machines were placed completely under the high roof, keeping the counter-shaft attached to the gallery or low bay. Of course, this construction made it very difficult to serve the low bays by traveling cranes. Special constructions and special arrangements of travelers or jib cranes were required to overcome this difficulty, in many shops; but whatever arrangement was used, it was always more or less special, and a change of conditions in such a shop caused either a great deal of inconvenience, or else, extensive changes in the arrangement of machine tools and cranes. It was readily recognized that a universal arrangement of shops and equipment was missing, and it was equally readily recognized that a motor drive for machine tools would make such a universal arrangement possible.

Very soon after the first introduction of electric motors for machine-tool drives, portable machines and the floor-plate system of machining were introduced. Heretofore, portable machines could only be used by means of flexible shafting and, of course, this system was necessarily very much limited. Electric motors were especially applied to portable boring machines, slotters, milling machines, etc., and to punches and shears for boiler shops and shipyards. Lack of understanding of the requirements of such machinery and of the possibilities and limitations of electric motors, caused a great deal of dissatisfaction and failure in the early machine-tool drives. However, the great merit of the electric-motor drive was recognized, notwithstanding the large percentage of failures. The electric motor was the cause of a better understanding of requirements of machine tools, and the recognition of the limitations of the electric motor was the cause of improvement in the motor, which has brought it gradually to the present high degree of efficiency for

machine drives. It may be said that the motor and machine tools have influenced each other mutually.

Applying motors to portable tools made these tools so much more useful that the problem of providing more power for them hardly entered at first. Almost any speed or any amount of power which the motor might give to the tool was more than it had had theretofore, and, therefore, the electric drive of the portable tools was successful from the start. One of the first applications of electric motors to machine tools was the planer drive. The planer was considered an especially inviting field for the motor, because it would make it possible to place the planer in a better position in the shop. Considering that the planer at all times is a first-operation machine, and, relatively speaking, is always a large machine, and that practically all large forgings or castings must go to the planer at one time or another, it was very important to have the planer where it could readily be served by an overhead crane. The electric drive of the planer was, however, not a success at first, and, in fact, has not been a complete success until quite recently, when the reversible motor was applied to the planer.

The amount of power required by machine tools has been, practically speaking, an unknown quantity. Little attempt had been made to ascertain the relation between size of cut and the amount of power required, and there were only very vague ideas in circulation as to the pressure at the tool point for a given cut. The difficulties in the way of clean-cut tests to determine the amount of power were very great. The introduction of the electric motor made it possible to find the power for a machine drive with a high degree of accuracy and one of the first results of the introduction of the motor was, therefore, a better understanding of the power required by machine tools and the strains and stresses developed in their members.

It is probable that less attention would have been paid to the requirements of machine tools if it had not been for the introduction of high-speed steel, which made a demand on existing machine tools much in excess of their power. Trying to fit the machines to their new duties led to the making of tests, and a motor drive made these tests possible. It may be said, with a fair degree of accuracy, that all the existing knowledge

in regard to machine tools so far as power, pressures, etc., is concerned is due to the electric motor as driving power for machine tools.

What is true of our knowledge of power, is also true of our knowledge of speeds of machine tools. Introduction of high-speed steel made it necessary to acquire some knowledge on this point, and the introduction of the electric motor made it possible to acquire that knowledge. It should be pointed out, that, in this respect, the machine tool has influenced the electric motor at least as much as the motor has affected the machine tool. At a very early date in the history of the application of the electric motor to machine tools, it was found desirable to control the speed of a machine tool very closely; and almost at the very beginning of the introduction of the electric motor, attempts were made to electrically control the speed of a machine tool. The systems used to accomplish this were very crude and show conclusively that the electrical and machine-tool people did not understand each others' requirements. Series-wound motors were applied where shunt-wound motors were required; the speed of shunt-wound motors was regulated by means of armature resistance, etc. Though the errors thus made were very glaring and were understood by some even at that time, the very ignorance existing on these points was beneficial, for the thought that it was possible to control the speed of a motor brought home the desirability of controlling that speed and made the machine-tool builder see visions of building the motor into his machine. In fact, some of the earliest applications of the electric motor to machine tools went further in this respect than anything that has been done since. Special motors were designed to fit into the head-stock of lathes and other machines, and though these attempts were necessarily failures, they established an ideal toward which later designers have been working.

It may be said, in general, that the electric motor has influenced the machine tool beneficially along the following lines:

(A) Better knowledge of the data governing the design of machine tools

(B) Greater possibilities in regard to power

(C) Closer control of a machine tool in regard to speeds, stopping, starting, etc.

(D) Flexibility of the use of machine tools, by making them portable and by making a better shop construction possible

When speaking of the influence of the electric motor on machine tools, it is well to recognize, at the start, that the motor has been influenced by the machine tool to a certain extent, as a result of its influence on the machine tool. In other words, the influence has been mutual.

In the early days of the application of the electric motor to machinery, very little effort was made on the part of motor builders to have their product suitable to the machine to which it was to be applied. This was true in regard to the electrical characteristics as well as to the mechanical construction of the motor. The constant contact with the problems of application of motors made the motor builders put forth their best efforts in improving the motors, so as to make them more fit to their duties. It may be said, however, that the intrinsic design of electric motors has not been materially affected by their application, except in one particular. The demands of the various applications of the motor have led to the adjustable-speed motor in its various forms. For the rest, the influence of machines on the motor has been in the direction of mechanical design and workmanship. We may say that the influence of machinery on the electric motor has been an influence on its detail, but not on its general principles.

Quite the opposite is true with the influence of the electric motor on machine tools. The writer believes that the most marked and most beneficial influence of the electric motor on machine tools has been the bringing into view of the lack of fundamental knowledge of machine tools, and that it has opened up a new era for the machine tool, which may be called the scientific era.

Machine tools have been the product of the requirements of mechanics. They were simply contrivances to help the mechanic in his work. They were more or less highly developed implements. Their various features were products of development and evolution, rather than of invention. The scant

knowledge of their principles was the result of observation, rather than of experimentation. Mathematics had never been applied to machine tools. The stresses and strains to which machine-tool members were subject were not known. The forces required in a machine tool and the amount of power for certain work to be done in the machine tool were absolutely unknown, and, what is more, this lack of knowledge was not recognized as such. It is due to the electric motor that this condition of affairs in regard to machine tools has become recognized and that efforts have been made to put their design and application on a more scientific basis. It must also be stated here that very little has been done, so far, along this line. Nevertheless, we must thank the electric motor for the fact that we are now aware of our ignorance and are at last put in a position to seek for knowledge and data on which a theory of machine tools may ultimately be built.

The electric motor has brought this about because it made it possible to measure with a fair degree of accuracy the power required for the drive of machine tools. Practically speaking, absolute ignorance existed twenty years ago in regard to the power consumption of individual machines. A few dynamometer tests had been made to ascertain the power transmitted by some driving belts, but the conditions under which the tests had been made did not allow of careful instantaneous measurement, so that the best that could be done was to get some general idea of the average amount of power consumed by some machine tool. The simplicity of the method of determination of the power consumption by an electric motor, and the possibility of not only following with the eye but actually recording fluctuations in this power consumption, led to a great many tests in a very short time and produced more accurate knowledge of power conditions in machine tools than had ever been brought to light before. By observing speeds at the same time, valuable data were obtained in regard to slippage of belts, so that the knowledge of the properties of belting for power transmission was vastly increased. One of the first results of these tests was to show up the fact that the capacity of belts for power transmission had heretofore been under-estimated. Shortly before the introduction of the electric motor on ma-

chine-tool drives it was considered that forty pounds pull per inch of double belt was correct. Shortly after the introduction of the electric motor, fifty pounds was considered proper for single belts and sixty pounds, or even more, for double belts, and it was further discovered that under special conditions the capacity of a belt might go very much higher.

It is doubtful whether the machine-tool builders would have taken the full advantage of this possibility of determining the power of machine tools, if it had not been that necessity drove them to it. This necessity was brought about by the fact that simultaneously with the introduction of the electric motor came high-speed steel, which made it possible to take cuts in metal theretofore deemed impossible or, at least, impractical. The demand for increased power and speed made it absolutely necessary to determine the relation between the metal-cutting capacity of a machine tool and the power required to drive it. Shortly after the introduction of high-speed steels, machine tools were built for similar purposes but with entirely dissimilar drives, one maker recommending perhaps a five-horsepower motor, while another maker would recommend for the same machine a fifteen- or twenty-horsepower motor.

It was soon found that the relation between the amount of cut and the amount of power was not so simple as it was at first supposed to be. Not until Mr. Taylor's work on the "Art of Cutting Metals" was published was it generally recognized that a great many elements would affect this relation, and even today there is very little positive knowledge in regard to this relation. Nevertheless, it may be said that the electric motor gives us the means to investigate this relation scientifically, and, at the same time, the electric motor should be given credit for having started this investigation.

Not only the power for the drive, but also the power required for the feed was more closely investigated, and, as a result of the new knowledge, it became possible to design the members of machine tools more nearly along scientific lines, thus producing better proportions of the parts of machine tools. It became possible to measure deflection of parts of the frames under given pressures or under given conditions of work, and much has been learned in regard to rigidity or lack of rigidity

of machine tools. However, we are only at the beginning with all of these things. The work of studying the subject has been left almost entirely to the individual makers or users of machine tools, though here and there universities and colleges have taken up this line of investigation and have helped it along. It is the great desire of the writer to see, at some time, the study of machine tools taken up in universities and technical colleges with the same amount of earnestness and thoroughness which has been devoted to the study of steam and steam engines, or of the electric motor itself. He believes that such a study will lead to surprising results.

When we consider that the work of a machine tool consists merely in removing a part of a piece of metal and when we calculate the amount of power required to remove this metal under ideal conditions, we notice that only a small fraction of one per cent of the total power given to a machine tool is utilized for the actual removal of the chip and that all the rest of the power applied is lost, partly for the driving of the machine itself, though only a small part, but mostly for doing several things to the chip after it is removed; things which have no beneficial effect on the ultimate work.

It is the writer's opinion that by far the greatest effect of the electric motor on machine tools has been in the direction of bringing machine-tool problems before the eye of the machine-tool designer in a definite and tangible manner, and in having led to the first steps in the direction of investigation and collection of data. It has taken the machine tool, to a certain extent, out of the hands of the workman and has put it into the hands of the investigator. In short, it has put the machine-tool business on a scientific basis.

The electric motor has further increased the possibilities of machine tools by removing the limitations due to the manner of driving the machine. The conditions under which machine tools have to be operated do not permit of belts of unlimited width. The possible power which could be given to machine tools was, therefore, limited. The problem of supplying sufficient power to machine tools was brought to the foreground when high-speed steels were introduced.

The first use which machine shops made of high-speed steel

was to speed up their machines, in other words, take cuts at a higher speed, leaving feeds and depth of cut much as they had been before. This was done by the simple expedient of running the line-shaft or counter-shaft at a higher speed. The machine tools, not having been designed for this higher speed, would naturally cause a number of troubles. Besides, it was found that better results could be obtained by not attempting to run the cutting speed up too high, but by increasing the feed and depth of cut. The second stage of the application of high-speed steels was almost entirely in that direction, but this required a much increased driving power for the machine tool. Various methods were employed to reach this result, such as speeding up the machine tool and then using the lower speeds almost exclusively; but even then it was found that the existing machine tools would not permanently lend themselves to the increased production and, gradually, new designs of machine tools were brought out to meet the requirements of high-speed steel. The chief difference with the older types of machine tools was the increased driving power, and the difficulties encountered by trying to get this increased driving power out of a belt led almost immediately to the application of the electric motor.

However, there was one item in which the driving belt had the advantage over the electric motor. The driving belt could be made shifting and thus supply the necessary changes of speeds, whereas, in the early stages of the application of the electric motor to the machine tool, there was no motor of which the speed could be properly changed. It is the opinion of the writer that the demand of machine tools led to the development of the adjustable-speed electric motor.

At first, various systems were used which have now all been abandoned, such as speed control by armature resistance, the use of series-wound motors, the multiple-voltage system, and the three-wire system. They have now all been supplanted by the adjustable-speed motor with field control. The limitations to the extent of possible field control have led to the interpole motor in its various forms.

It seemed for some time that the adjustable-speed electric motor would solve the problem of speed range in a machine tool. However, the development of the alternating-current

motor which does not yet permit of speed regulations in a manner required by machine tools, made it necessary to devise other means of governing the speed of machine tools.

Economical reasons made it absolutely necessary for machine-tool builders to reduce the number of types of their machine tools. It was not very well possible to develop one type of machine tool for belt drive, another type of the same tool for a direct-current adjustable-speed motor drive, and still another type of this same tool for an alternating-current motor drive. At first, this was actually done, and all motor-driven tools were, more or less, the varieties of the belt-driven tool. It was the belt-driven tool with a motor attached. As a result, this attaching of a motor was in the nature of a makeshift. Various forms and types of motors were attached in various ways. Of course, this could not be a lasting condition, and it was not long before various machine-tool makers made an attempt at designing their machine tools in such a manner that they could be driven according to the needs of the user, either by belt, by alternating-current motors, direct-current one-speed motors, or adjustable-speed motors.

At first, the adjustment of the speed, when using an alternating-current motor, was obtained by interposing the countershaft with a belt cone, just as had been done in the original construction of the machine tool; but, gradually, all machine tools drifted into the way of using the electric motor as a driver only, and having the speed-adjusting mechanism, in the form of gearboxes or similar devices, as part of the machine tool.

The application of mechanical speed-changing devices to machine tools has led to important changes in the construction of their frames. The best machine tools, as made nowadays, are much more self-contained and have much more rounded out and more rigid frames than were to be found in the older types. It must be said here that the success of the gear-box or mechanical speed-changing devices is largely due to the automobile industry, which has developed materials and constructions suited for the purpose. The machine-tool industry was not and could not be of a sufficient magnitude to permit of the large amount of experimentation necessary to develop these materials and constructions.

The electric motor has had its effect on the machine tool along various lines. It has been pointed out that it has brought some positive knowledge to the machine-tool designer, that it has made it possible to derive the full benefits of the qualities of high-speed steel, that it has improved speed control, and that it has improved the construction of the frame of the machine, and, consequently, its rigidity. It has also made possible a number of improvements which make for convenience and safety. The design of belts and the guarding of gears, which were made necessary because the speed-changing device had to be properly lubricated and, therefore, could not run in the open, have increased the safety of machine tools; and the necessity of placing levers and shifting devices where the operator could conveniently reach them has added much to the convenience of handling.

In addition, the electric motor lends itself particularly well for auxiliary functions, such as elevating the cross-rail of a boring mill or planer, the quick traverse of the carriage of a large lathe, the quick traverse of milling-machine tables, etc. Though such quick traverse devices have been in use for many years, yet the application of the electric motor has made them so much easier of application and so much more convenient in the handling, that their use has been greatly increased.

One of the first effects of the application of the electric motor to machine tools has been the change in design of machine shops, making it possible to place the machine to its best advantage, without having to pay attention to the requirements due to the location of line-shafts and the possible location of counter-shafts.

Many of the above mentioned changes could have been made even if the electric motor had never entered the field of machine tools. Lathe head-stocks could have been made with gear drives and single belts just as well if no electric motor had existed. The advantages of such a construction would have been almost, if not entirely, as great as the advantage of the motor drive, but, as a rule, such changes in the construction of standard machines are not made unless some other change compels the maker to modify his design. This compulsion was brought about by the demand for electric drives and the inabil-

ity of the electric motor to furnish one of the features of the standard belt drive of machine tools. Two elements of the standard belt drive were, that, in the first place, the drive provided the necessary power for running the machine and, in the second place, it furnished in itself means for changing the speeds. The electric motor provided the first element so well that a strong demand was created for the application of the motor, and this made it necessary to provide the second element of the belt drive in some other form.

It will be found that, even at the present time, only a relatively small percentage of standard machine tools are motor driven, but that a very large percentage have benefitted by the changes which were required for a successful motor drive. It may be said that the single-pulley drive is a direct offshoot of the motor drive.

Paper No. 136

ELECTRIC WELDING.

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Electric welding cannot be considered as new from the patent standpoint since the fundamental patents, both in arc and incandescent welding, have expired. It may be said, nevertheless, that owing to the apathy displayed by the general public who have failed to appreciate the possibilities until comparatively recently, the art has failed to reach the stage of advancement it undoubtedly otherwise would have reached and accordingly further developments may not unreasonably be expected in due course.

Electric welding can be accomplished by any one of several processes but none of them is of universal applicability; that is to say, each one is more or less limited to a certain field as well as to a given range in such field. Furthermore, there is very little advantageous overlapping of their respective fields, so that the processes are supplementary to one another rather than complementary.

There are three clearly defined processes; namely, arc, incandescent and electro-percussive, of which the last mentioned is very recent. The first two of these are capable of sub-division; the arc into the Zerener, Benardos and Slavianoff processes; the incandescent into the La Grange-Hoho and Thomson processes. The differences between them may be briefly stated as follows:

1. **Arc** (direct current)	(a)	Zerener. Arc drawn between two carbon rods which form the electrodes and directed on metal to be welded.
	(b)	Benardos. Arc drawn between carbon rod, which forms one electrode, and metal to be welded, which forms the other electrode.
	(c)	Slavianoff. Arc drawn between metal rod, which forms one electrode, and metal to be welded, which forms the other electrode.
2. **Incandescent** (direct current)	(d)	La Grange-Hoho. Metals to be welded form one electrode of acidulated bath; large conducting plate forms the other electrode. Metals butted together after reaching incandescence.
(alternating current)	(e)	Thomson. Metals to be welded form the electrodes; butted together under pressure, causing high resistance contact with heating.
3. **Electro-percussive** (direct current)	(f)	Metals to be welded form the electrodes; brought suddenly into percussive contact and vaporized.

The arc processes are autogenous in that welding can be accomplished without pressure, simply by allowing the metals to melt under the influence of the electric current, then to mix and unite as they cool; the incandescent and electro-percussive processes, however, invariably require pressure as a necessary adjunct to their successful accomplishment.

ARC PROCESSES.

Zerener Process.

In the Zerener process the apparatus employed resembles certain types of direct-current flaming arc lamps, the carbons being inclined towards each other and automatically adjusted by a suitable mechanism as they are consumed. By means of an

electro-magnet, the arc, which is formed between the ends of the carbons, is directed downward in the shape of a pencil point. The metals to be welded are brought within the influence of the arc where they are then melted or fused as desired. Owing to the pointed appearance of the arc, which is rather like an oxy-hydrogen torch, the name "electric blowpipe" has been given to this apparatus. While it may be constructed so as to be held in the hand, or else suitably suspended for convenience of operation, the apparatus is complicated and does not lend itself readily to the carrying of large currents; for this reason it is apparently not used in America and to a very limited extent in other countries.

Benardos Process.

In the Benardos process, the arc is drawn between a carbon electrode, which forms one terminal of a direct-current circuit, and the metal to be welded, which forms the other electrode. The welding apparatus itself, aside from the current supply, is exceedingly simple, and there is, therefore, little to get out of order. As a minimum, 15 kilowatts at approximately 70 volts should be provided, though rather greater capacity is desirable especially when large work is likely to be undertaken. The voltage across the arc will ordinarily range from 40 to 50 volts depending upon the class of work.

Slavianoff Process.

In the Slavianoff process, the arc is drawn between a metal electrode, which forms one terminal of a direct-current circuit and the metal to be welded, which forms the other electrode. With this exception, the apparatus is very similar to that used in the Benardos process, although the minimum current supply necessary in this latter process may be said to be the maximum supply required in the Slavianoff process. The voltage across the arc is also lower in the Slavianoff than in the Benardos process, ranging from 18 to 30 volts.

Temperature of Arc.

The temperature of the carbon arc has been variously estimated to lie between 3500° and 4000° C., it being the hottest flame known, so that all metals may be readily melted by it.

In a direct-current carbon arc, the greatest energy con-

sumption and, therefore, the highest temperature occurs at the positive terminal, and may perhaps be explained on the theory that the vapor in the immediate vicinity of the positive electrode is of much higher resistance than that in the rest of the arc. This is exceedingly well shown by the curves in Fig. 1. No extended data have, however, been published on the performance of arcs in which one or both electrodes are of metal;

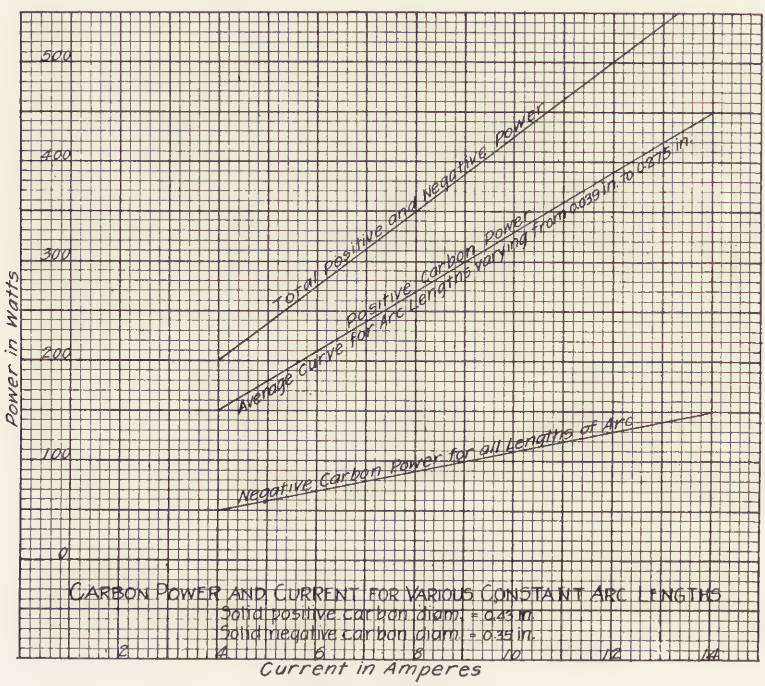


Fig. 1. Energy Curves for the Carbon Arc.

but, if the assumption be made that there is not a wide divergence between carbon and metal arcs in this feature, it is evident that different results should be obtained in welding when the metal to be welded is made the positive electrode than when the reverse condition exists.

When using the Benardos process, and making the metal to be welded the positive electrode, as is the practice, melting of the metal should and does take place at a faster rate than if

the carbon electrode were made the positive. In the latter case, it is exceedingly difficult to weld at all below 500 amperes. The reason for this may lie in the fact that the conductivity of an arc depends in great measure upon the kind as well as the quantity of vapor in it. As iron and steel are more readily vaporized than carbon and their vapors better conductors than carbon vapor, there is, for a given current and with the metal forming the positive electrode, a greater quantity of metal vapor in the arc than would be the case were the polarity reversed and therefore, current flows more readily from the metal to the carbon electrode.

In the Slavianoff process where both electrodes are of metal, the limitation just explained does not exist, and welding may be effectively done with either the work or the electrode as positive, though it is more usual to make the former positive. There might, however, be occasions when it would perhaps be of advantage to reverse these conditions and make the metal electrode positive so that the melting and therefore the deposition of metal would be more rapid owing to the greater heating effect at the electrode.

Apparatus.

In both the Benardos and the Slavianoff processes, there are required, in addition to the direct-current supply with its necessary controlling apparatus, electrode holders and electrodes, coverings for the operator and the work, fire clay or carbon blocks, etc., for moulding purposes, fluxes (?) and metal filling material.

Current.

Direct current, at approximately 70 volts for the Benardos and 50 volts for the Slavianoff process, is necessary and may be secured from any reliable source. If only a higher voltage is available, it may also be used, but is wasteful and only to be recommended where the amount of welding required is either so small or so infrequent as not to make advisable the installation of a separate outfit; and any excess voltage must first be reduced to the proper amount by the introduction of suitable resistance into the circuit. Satisfactory welds may be made in the Benardos process with 15 kilowatts capacity and even less; it is, however, preferable to have more where large pieces

are to be handled or where more than a single operator is to be employed, and similar reasons govern in the Slavianoff process. If current is obtained from an independent source, as is usually the case, instead of from public supply mains, the dynamo should be compound wound (although shunt may be used) with an over-compounding of about 5 per cent. Either a direct-connected motor-generator set or a belted outfit may be used, and while the latter has the marked disadvantage of occupying greater floor space, it has the compensating advantage of a flexible connection through the belt which tends, by its slipping, to relieve the strains on the outfit when the load is suddenly thrown on in closing the circuit by touching the electrode to the work.

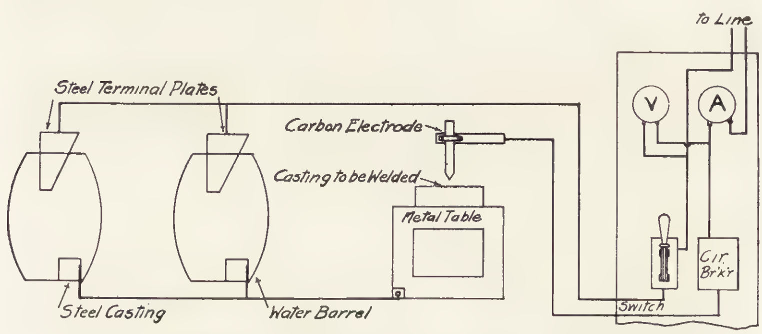


Fig. 2. Diagrammatic Sketch Arc-Welding Circuit, Benardos Process, Water Barrel Resistance.

Control.

There must obviously be some means at hand for controlling the current supply and the voltage across the arc, since welds of different kinds will require varying current strengths at varying voltages across the arc, and this is attained by the use, generally, of resistance introduced into the main circuit, though sometimes the same result may be secured by weakening the field of the dynamo. This latter method is, however, extremely limited in its application as it can only be used when a single operator is at work; otherwise, other operators on the same circuit would be seriously handicapped. Fig. 2 shows a complete circuit in practically its simplest workable form, and in which barrels of water are employed for resistance. As will

be seen from the diagram, current flows from the line through a single pole switch, then through the adjustable water resistance either direct to the material to be welded or to a metal table upon which rests the material. From this it passes through the arc, the electrode and its holder, then through a circuit breaker, an ammeter and back to the dynamo.

Metal resistance grids can be substituted with certain advantages for the water barrels, as the latter in time require to be replaced due to the hoops rusting away; furthermore, the water changes in resistance as it becomes heated, necessitating

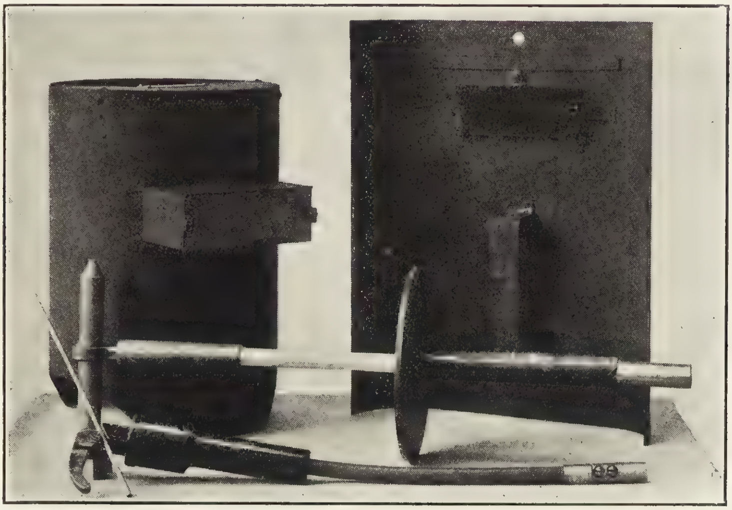


Fig. 3. Hood and Shield for Operator. Carbon and Metal Electrode Holders.

an occasional readjustment; and, finally, if the outfit is worked very hard the water boils over, involving a stoppage of work in order to allow the water to cool.

All other schemes of connections are but variations of the above, some making use of relays for cutting out resistance inserted in the circuit, whenever the arc is struck, to prevent burning of the work or destruction of the dynamo; others, to maintain a constant load and, therefore, a constant voltage on the dynamo at all times, thus tending to minimize fluctuations

in voltage when welding. In theory, such schemes may show to advantage over the simple diagrams of connections described; but, in practice it is reliability and simplicity that are essential above everything else, and a dynamo, when especially designed for welding, should withstand such loads as are thrown upon it. Furthermore, there is absolutely nothing in the statement sometimes made that extra resistance is required in the circuit when striking the arc to prevent burning of the material; but, if there were, the arc could readily be struck adjacent to the place to be worked upon, or even upon a flat metal plate nearby and in contact with the material, and then moved to the position wanted without breaking the arc and thus eliminate so-called burning of the metal. Still further, too much stress is laid upon efficiency, whereas it is of secondary importance since current is drawn from the dynamo only at irregular intervals, possibly averaging 15 to 30 minutes out of every hour even when the outfit is in constant service.

The table, given below, is the record of three oscillograph tests made to determine the electrical data of the welding operation:

Results of Oscillograph Tests—Electric Arc Welding.

Test No.		9	10	11
(b)	Type of electrode	Carbon	Iron	Iron
(c)	Size of electrode, diam. inches	¾	¼	¼
(d)	Resistance in series with arc, ohms.	.0709	.296	.296
(e)	Voltage of welding circuit, volts	46	67.5	65.0
(f)	Theor. max. current, striking arc, amps.	650	228	See note
(g)	Actual max. current, striking arc, amps.	390	205	....
(h)	Average welding current, amps.	300	155	....
(i)	" drop across arc, volts	23	22.5	0
(j)	Time to strike arc, seconds	.07	.06	....
(k)	Ratio of (f) to (h)	2.17	1.48	....
(l)	" " (g) " (h)	1.3	1.32	....

Note—In "11" electrode was allowed to stick or "freeze". Current gradually rose from 215 amps. to 250 amps.

Electrodes and Holders.

Fig. 3 shows two types of electrode holders, one for the Benardos process where a carbon rod is used, the other for the Slavianoff process where a metal rod is substituted for the carbon electrode. In both, the holders consist simply of metal receptacles suitably insulated for gripping by the hand, the electrodes being designed to take rods of various diameters.

Carbon electrodes will range from $\frac{1}{4}''$ (6.35 cm) to $1\frac{1}{2}''$ (3.810 cm) in diameter by $6''$ (15.24 cm) to $12''$ (30.48 cm) in length, depending upon the class of welding, whether large or small, and both of these higher limits may be exceeded in certain cases. The carbons should be solid, not cored, should neither crack, crumble nor spindle, and should preferably be "graphitic" rather than "common" as the former type is of higher electrical as well as thermal conductivity.

Metal electrodes will range from $\frac{1}{8}''$ (.3175 cm) to $\frac{5}{16}''$ (.7938 cm) in diameter, by approximately $12''$ (30.48 cm) in length, likewise depending upon the class of welding. For welding in wrought iron and steel, nothing can excel the genuine Norway or Swedish iron.

Covering for Operator.

Electric welding, more especially when effected by the Benardos or carbon arc process, requires, on account of the brightness of the arc, to be done in an enclosure so that any other work going on in the vicinity will not be interfered with. The operator must also be thoroughly well covered over the entire body, head, eyes and hands. Exposure to the arc rays, even if but of brief duration, causes an irritation or inflammation closely resembling sunburn, but fortunately with no more serious consequences.

In Fig. 3 are shown two types of hoods, the one on the left for carbon electrode welding where it is necessary to envelop the head completely; the one on the right for metal electrode welding, where by simply holding the hood in front of the face, sufficient protection is afforded due to the very small arc.

Particular attention is called to the distance the glass window projects from the hood and which experience shows to be necessary to keep the heat away from the eyes. Hoods may be made of canvas, sheet-metal or insulating material and

should be thoroughly well ventilated. The clothing is sufficient protection for the body and gloves for the hands.

Regarding the eyes, as they are so much more sensitive, even greater care should be taken in their protection. Until a comparatively recent period, it was assumed that any colored glasses which apparently enabled the operator to look steadily at the arc, afforded proper protection, and when a combination of ordinary colored glass met this specification, no further thought was given to the matter. Without going into any more detail, it may be said that authorities now state that the eyes should be protected (a) from ultra-violet rays, owing to the destructive effect upon animal tissue; (b) from infra-red rays, which, being heat rays, are surmised to be the cause of eye fatigue and other eye troubles; (c) from excessive brightness because of the blinding effect; and (d) from mechanical injury. This protection can be successfully accomplished by the use of specially prepared glass, suitably mounted, which cuts off the ultra-violet as well as the infra-red rays, and which is at the same time of sufficient density to prevent excessive brightness.

Fluxes.

A great diversity of opinion seems to exist as to the value of fluxes, and many operators have their own secret formulae. It may be stated, however, that no flux is needed for welding either wrought iron or steel, the field to which arc welding has thus far proved to be particularly adapted.

Filling Material.

For welding wrought iron or steel, various filling materials may be used, among them being Norway—or Swedish—iron rods, boiler iron, scrap, bits of steel castings, etc.; for cast or malleable iron, Norway—or Swedish—iron rods or special cast iron rods with a high percentage of silicon.

Welding.

In the Benardos process, the carbon electrode must, as already stated, be connected to the negative terminal of the circuit, the metal to be welded to the positive terminal either directly, or if more convenient, indirectly by being laid upon a metal table, Fig. 2, to which the positive terminal has previously been connected. In the Slavianoff process, welding

may be effected regardless of the connections. It is customary, however, as already stated, to make them the same as in the Benardos process. The resistance of the circuit should next be adjusted to what is deemed to be the proper amount, after which the circuit-breaker or relays and the line switch are closed. The operator then takes his position with the electrode holder in one hand and the hood (for the Benardos process) or the shield (for the Slavianoff process) in the other. Bringing the electrode as close to the metal to be welded as possible without actually touching it, he then pulls the hood down over his head or raises the shield in front of his face, touches the electrode to the work and instantly pulls it away the required distance, thus striking the arc, which, when a metal electrode is used, will approximate $\frac{3}{16}''$ (.4763 cm) while when a carbon electrode is employed, will vary from $\frac{1}{2}''$ (1.27 cm) to $2''$ (5.08 cm) or even more in length according to the work being done.

Whether or not the resistance has been properly adjusted will be readily determined by the behavior of the arc; if too fierce, the resistance in the circuit is insufficient and should be increased, while if too weak, failing to maintain itself, the resistance is too great and should be decreased.

In using the carbon electrode, the arc should be given a rotary motion by hand, thus heating the metal to be welded more uniformly and preventing burning. It should also be borne in mind that the longer the arc, the less chance there is of carbon entering the metal and producing a hard weld. When the metal reaches a molten condition, filling material is added to it, little pieces at a time, the arc being interrupted only just long enough to add such material, then being struck and played upon the mass again; or the filling material can be used in the form of a long rod, one end of which is inserted in the molten metal and the arc played upon it until the end is melted off and fused with the mass.

In working with the metal electrode, rather more skill is required in striking the arc than when the carbon electrode is used; for if the electrode is not instantly pulled away, it will stick to the work, or if pulled too far away, the arc will go out. As the arc may be as small as $\frac{3}{16}''$ (.4763 cm), and pos-

sibly less, it will be appreciated that the limits are rather close in which to manipulate it successfully.

When the welding involves the building up of a lug or projection, this can be accomplished by the use of a supporting rim of suitable shape, made either of sheet copper, fire clay or carbon blocks, although it is preferable to avoid, if possible, the two latter since they are liable to soften and mix with the weld.

In joining two pieces of any but thin sheet metal together, the abutting edges should first be chamfered at an angle of about 45° either from one or both sides, depending upon the thickness of the material, and the chamfer should extend entirely through.

As soon as the weld has been completed and while still at a white heat, it should be briskly hammered in order to give the metal a finer grain. All oxide and other impurities should, of course, be kept out of the weld. It is, therefore, important that the materials be thoroughly clean and free from slag and dirt, not only before commencing to work, but at all stages. The metal to be welded should accordingly be chipped or machined in the vicinity where the weld is to be made; or the same result may be accomplished by tilting it to a suitable angle, then turning the carbon arc upon it and allowing the slag, in melting, to fall away by gravity.

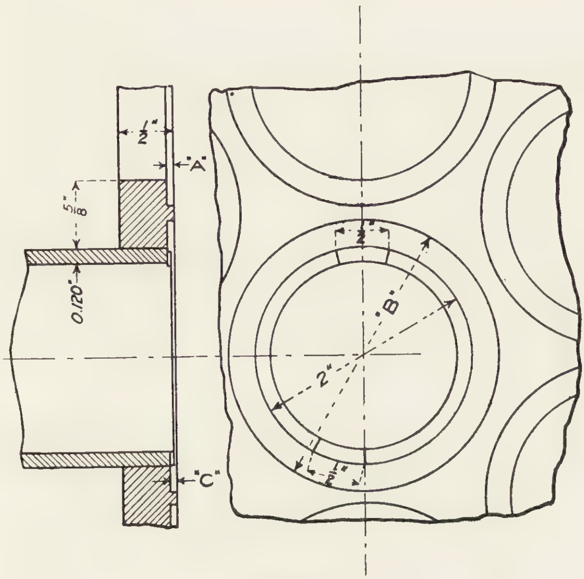
Heating the metal preparatory to welding is always beneficial as preventing and relieving strains, but is not resorted to except in special cases. A temporary furnace, especially for large work, is easily made when needed, by laying a loose flooring of fire-brick without mortar of any kind on which is placed the metal to be welded; walls and roof are then built, iron bars being laid across the roof at proper intervals to support the bricks. Suitable ports which can be uncovered, are provided, through which the electrode may be inserted. After the metal to be welded has been preheated in the usual manner to a white heat, the ports are uncovered, the electrode inserted and the weld made. The ports are then covered and the welded piece allowed to cool.

Annealing is also desirable at times but like preheating, is not done except when absolutely necessary.

A very decided economy can sometimes be effected by repairing a defect discovered during a machining operation, by making the repairs without removing the piece from position.

Flue Welding.

The welding of flues in locomotive boilers offers a most fertile field for the Slavianoff, or metal electrode process. Sev-



NOTE.

"A".... This cut only made deep enough to clean sheet of all scale and make right angle at edge of flue hole.

"B".... From $2\frac{1}{2}$ to $2\frac{3}{4}$ inches, depending on condition of sheet.

"C".... From 0 to $\frac{1}{16}$ inch.

Fig. 4. Flue and Flue Sheet Prepared for Welding.

eral different methods of preparing the flues and the flue sheet preparatory to welding are in use, one of the most promising being that developed by Mr. O. C. Wright, Asst. Engineer of Motive Power of the Pennsylvania Lines (West). Referring to Fig. 4, the flue sheet is first countersunk around each flue hole for a width of ¼″ (.635 cm) to ⅜″ (.9525 cm) and to a

depth necessary to give a surface of clean metal and a feather edge at the flue hole. The flues are next driven into position in much the usual manner except that no copper ferrules are required, nor is it necessary to swell the flues just back of the flue sheet; further, the flues should project above the countersunk surface of the flue sheet not to exceed $\frac{1}{16}''$ (.1588 cm) at any point and the flue rim should be cut away, both top and bottom, through an arc of about $\frac{1}{2}''$ (1.27 cm) as shown. In making a weld, current of approximately 90 amperes at 18 volts across the arc is employed, the welding commencing at the bottom and working around to the top for each half. Care should be taken to play the arc on the flue sheet immediately adjacent to the flue, rather than on the flue directly, and it is also preferable so to proportion the length of the welding rod, which should be of $\frac{5}{32}''$ (.3970 cm) diameter Norway iron, that each half of the weld will be made with a single electrode and if possible with one application of the arc. No flux is necessary. Including the cutting away of the rim, about twelve flues can be welded per hour.

Flues welded in this manner have been tested to destruction by the method shown in Fig. 5, withstanding a crushing force of over 30 tons (27,200 kg) along the axis of the flue at which pressure the flue itself failed; this as against 17 tons (15,400 kg), at which pressure flues applied in the usual manner are found to fail.

Metals Which Can be Welded.

Both of the electric arc processes are particularly well adapted to the welding of wrought iron and steel of various kinds; and, while certain other metals including cast iron can also be welded, the work is not, generally speaking, done to any advantage over some of the other processes. Welds in cast iron will prove quite variable when made by the average operator, being frequently glass hard (though this may not matter where no machining is done) and uncertain as to strength, so that at the present time, it would be rather unwise to make any pronounced claims for arc welding in this connection. With malleable iron, the results obtained are even more variable than with cast iron. In the welding of cast iron, very good results are obtained by the use of the carbon electrode

process with a suitable cast iron filling rod, first preheating the metal to white heat, making the weld while in this condition and then cooling gradually.

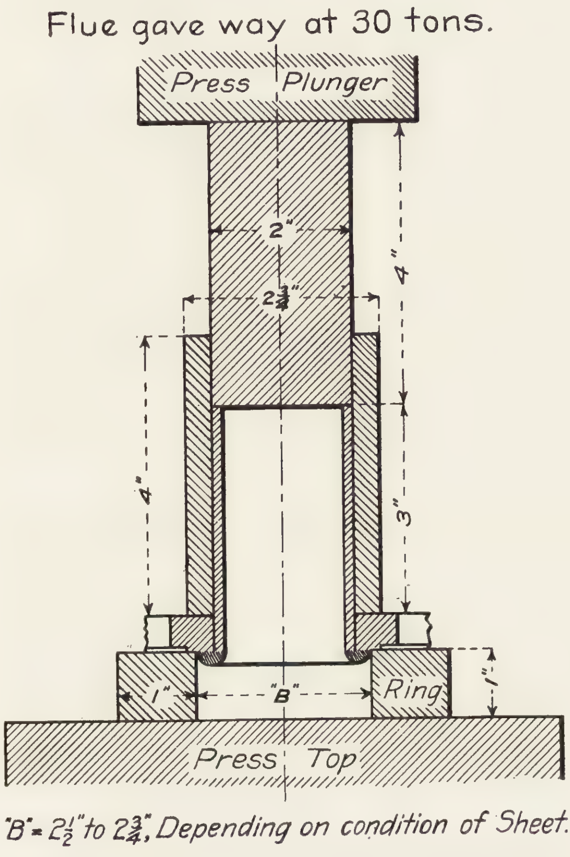


Fig. 5. Method for Testing of Locomotive Flues.

Comparison of Arc Processes.

With the Benardos or carbon electrode process, in general, more welding can be performed in a given time than can be accomplished with the Slavianoff or metal electrode process; and viewed from this standpoint alone, the former is the cheaper. As with cast iron, the welds will, however, at times be decidedly

hard, so much so as to be occasionally impossible of machining, due to carbon from the electrode entering the metal; but when no subsequent machining is necessary, hardness is no disadvantage; and, in some kinds of work, such, for example, as the rebuilding of the ends of rolling mill wabblers, pinions, etc., this very condition is a decided advantage.

In the Slavianoff process, the difficulty of hard welds is largely overcome owing to the use of the metal electrode; the welding of thin sheets can be more readily done and, in fact, a finer grade of work of the lighter kinds performed than with the Benardos process; finally, the ability to reverse connections may be an occasional advantage.

The Slavianoff process is confined strictly to welding, while the Benardos process is used both for welding and cutting as well as for heating under certain conditions.

Cutting.

Cutting of wrought iron and steel can be very successfully done with the Benardos or carbon arc process, though the cut will be wider and the edges not comparable in smoothness with any of the oxy-gas cutting processes. However, where electric current is readily available and the finish of the cut is not of especial importance, as in the removal of sink heads and risers from steel castings, it is probably one of the cheapest methods for such work, since almost no time need be spent in setting up the casting in position as is necessary when cutting by machine or hand. Various authorities give the rate of cutting as being from one-half (3.226 sq. cm) to one square inch (6.451 sq. cm) per minute per 100 amperes with a minimum of 300 amperes. Fig. 6 shows, however, that the rate of cutting approximates more nearly the lower limit.

Other Applications of the Arc.

The electric arc processes of welding were originally largely confined to repair work in wrought iron and steel, but since becoming better understood, their uses are extending; for example, surplus metal including fins, risers, sink-heads and nails are easily removed from steel castings, holes are bored in wrought iron or steel plates, wrought iron or steel pipe sections are readily joined together or flanged, the ends of wrought iron rings are welded, wire nails may be pinned to

wrought iron or steel plates, tap holes or tuyères in furnaces are opened, broken drills and taps are easily removed from castings, etc.

Opening of Tap Holes.

In the opening of the tap hole or a tuyère of a cupola, the Benardos process is employed. The furnace is made the positive terminal, the negative terminal consisting of a rod of carbon 2″ (5.08 cm) or 3″ (7.62 cm) in diameter by about 48″ (121.92 cm) in length, fitted securely to a holder of wrought

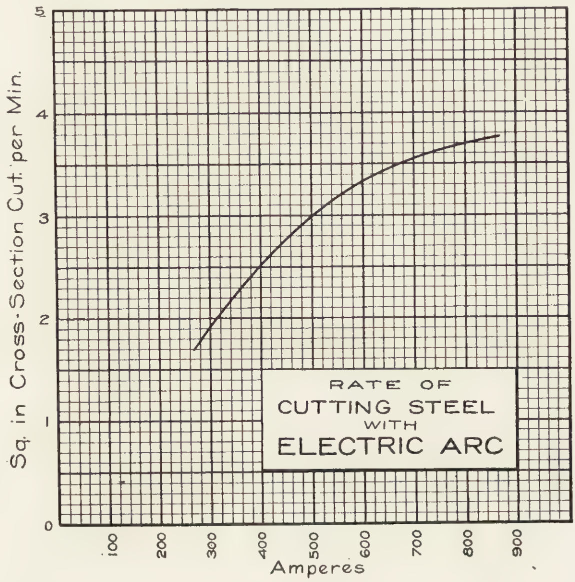


Fig. 6. Rate of Cutting with the Electric Arc Using a Graphite Electrode one inch in Diameter.

iron or steel pipe ten feet (3.048 m) or more in length and suitably insulated so that it can be readily handled. In other respects, the circuit is as already shown in Fig. 2. If a cinder is met during the burning, it is necessary to drive into it an iron bar until fused iron is encountered, as cinder is an insulator, after which the arc is sprung between this iron bar and the carbon electrode and the operation resumed. Great care must be used so that, as the operation nears a finish, molten metal will not

be blown out upon the operator. A current of about 800 amperes is recommended for such work, and with this the burning will be at the rate of approximately 30″ (76.2 cm) per hour.

Statistics.

It is exceedingly difficult and, in fact, impossible to make any absolute statements in connection with costs, speeds, most economical and efficient currents, best sizes of electrodes, strengths of welds, etc., on account of the many variables involved, such as skill of operator, fluctuations in current and rate of work, differences in composition of filling material and metal to be welded, so that the data here given are offered, in the main, simply as results which can be easily duplicated by the average operator and not necessarily as extreme in any respect.

Costs.

Blacksmith versus Carbon Arc Welded Rings—

The following figures have been obtained in the works of the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.:

Sections	Smith Welds*	Arc Welds*
1″ x 1½″ (2.54 cm. x 3.81 cm.)	$0.59	$0.51
1¼″ x 1½″ (3.175 cm. x 3.81 cm.)	0.66	0.30
1½″ x 2″ (3.81 cm. x 5.08 cm.)	1.13	0.45
1¾″ x 2½″ (4.345 cm. x 6.35 cm.)	1.25	0.45
2″ x 6″ (5.08 cm. x 15.24 cm.)	3.05	0.85

The following figures were supplied by one of the large American railroads, being taken from actual jobs at various times and compared with that of restoring the apparatus to service by previous methods, either by replacement or repair. The arc welding costs were based on an hourly power cost of 51 cents for the carbon arc and 17 cents for the metal arc, together with the cost of direct labor and an overhead charge of 40 per cent. The power costs are somewhat higher than those obtained in average work.

* Labor costs only included in above.

	Operation	Cost of welding	Cost of replacement or repair by former methods
1.	Welding tender draft casting	$ 1.11	$ 18.31*
2.	" tender center draft casting	4.36	19.06*
3.	" tender draft arm	1.11	19.08*
4.	Plugging 51 holes in expansion plate, hole 1" (2.54 cm.) dia. x ½" (1.27 cm.) deep	2.75	10.15
5.	Repairing mud ring	6.50	34.57‡
6.	Building up flat spots on locomotive drivers	.40	225.00†
7.	Building up four piston valve flanges	9.52	24.20*
8.	Repairing mud rings	5.57	32.70‡
9.	Plugging four holes 2" dia. (5.08 cm.) x 4" (10.16 cm.) thick	1.16	4.44
10.	Cutting four 6" (15.24 cm.) holes in tender deck sheets ½" (1.27 cm.) thick	1.08	8.35
11.	Plugging holes in two driving box cellars	.55	2.55
12.	Welding eccentric strap, broken through neck	1.08	41.28*
13.	Building up jaws of two pedestal caps	3.49	10.00
14.	Welding one driving box for type K-2 locomotive, broken through crown	5.75	39.31*
15.	Welding frame stiffener on locomotive	3.29	14.73
16.	Welding main rod, broken through end	6.35	70.49*
17.	Repairing fire box	134.89	869.58§
18.	Welding two spokes in trailer wheel center	7.72	68.05*
19.	Welding two spokes in driving wheel center	7.98	99.98*
20.	Welding three spokes in driving wheel center	11.20	126.60*
21.	Welding two spokes in driving wheel center	5.13	112.09*
22.	Welding cracks in bulk head in tender tank	2.33	8.00
23.	Welding cracks in side and door sheets of fire box	4.23	24.35‡
24.	Welding bridge in flue sheets	2.88	20.12‡
25.	Welding cracks in side sheets	26.15	31.79
26.	Repairing air drum	2.83	12.64*
27.	Welding guide yoke	1.68	16.15‡

* New parts required.

‡ Repair.

† Estimated cost to turn down all drivers as would otherwise be required. This would mean also the loss of at least one year's wear on the tires.

§ New fire box required.

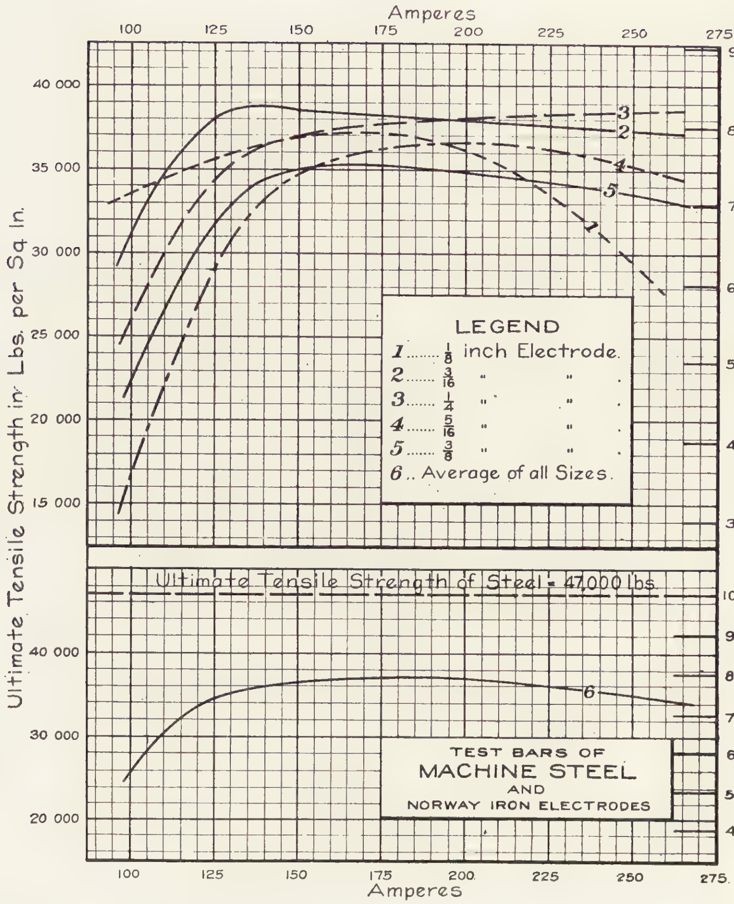


Fig. 7. Curves of Current and Strength. Machine Steel Welded with Norway Iron Electrode.

Speeds of Welding and Cutting.

(1) Filling drilled hole in cast steel axle cap. (W. E. & M. Co.)
Size of hole 1¼″ (3.15 cm.) dia. x 2″ (5.08 cm.) depth.
Size of carbon electrode 1½″ x 6″ (3.81 cm. x 15.24 cm.).
Current 500 to 650 amperes.
Time 56 seconds.

(2) **Welding sheet-steel seams (Cravens).**

GAUGE		Metal Electrode, Diameter		Current	Rate of welding	
BWG or In.	Cm.	BWG or In.	Cm.	Amperes	Ft. per hr.	Meters per hr.
28 to 20		18		10 to 25	30	9.14
18 to 1/8	.3175	1/16	.1588	20 to 40	25	7.61
1/8 to 3/16	.3175 to .4763	3/32	.2382	30 to 60	20	6.09
3/16 to 1/4	.4763 to .635	1/8	.3175	50 to 100	15	4.57
1/4 to 3/8	.635 to .9525	5/32	.3970	75 to 150	10	3.04
Over 3/8	.9525	5/32	.3970	150 to 180	variable	

(3) **Burning hole in wrought-iron plate. (W. E. & M. Co.)**
Size of hole, 1¾″ (4.345 cm.) dia. x 1½″ (3.81 cm.) depth
Size of carbon electrode, 1½″ (3.81 cm.) x 6″ (15.24 cm.)
Current, 370 to 1000 amperes
Time, 3 min. 30 sec. (includes 45 seconds for reversing plate)

(4) **Removal of sink-head from cast-steel axle cap. (W. E. & M. Co.)**
Size of sink-head, 2¼″ (5.715 cm.) x 6″ (15.24 cm.) area = 13.5 sq. in. (87.2 sq. cm.)
Size of carbon electrode, 1½″ x 6″ (3.81 cm. x 15.24 cm.)
Current, 600 to 850 amperes
Time, 4 min. 45 sec. (includes time for set-up)

(5) **Cutting Steel with the Electric Arc. (W. E. & M. Co.)**

Using a graphite rod 1″ (2.54 cm.) in diam. as the negative electrode.

Rate of Cutting

Size of section cut		Area Cut		Cutting current	Cutting time	Cross section Cut per min.		Cross section cut per min. per 100 amperes	
In.	Cm.	Sq. In.	Sq. Cm.	Amp.	Min.	Sq. In.	Sq. Cm.	Sq. In.	Sq. Cm.
8x8	20.32x20.32	64.	413.	810	27.00	2.37	15.3	.293	1.89
8x8	"	64.	"	600	41.75	1.53	9.9	.255	1.645
8x8	"	64.	"	320	98.00	0.65	4.2	.203	1.31
6x6	15.24x15.24	36.	232.	810	14.50	2.48	16.0	.306	1.975
6x6	"	36.	"	600	21.67	1.66	10.7	.277	1.71
6x6	"	36.	"	320	44.33	0.81	5.2	.253	1.63
4x4	10.16x10.16	16.	103.	810	4.70	3.40	21.9	.420	2.71
4x4	"	16.	"	600	5.62	2.85	18.4	.475	3.06
4x4	"	16.	"	320	10.08	1.60	10.3	.500	3.226
2x4.5	5.08x11.43	9.	58.	810	2.50	3.60	23.2	.445	2.87
2x4.5	"	9.	"	600	2.53	3.56	23.0	.577	3.72
2x4.5	"	9.	"	320	5.05	1.78	11.5	.557	3.59
1.375x3.25	4.345x2.55	4.47	29.	810	1.10	4.06	26.2	.502	3.24
1.375x3.25	"	4.47	"	600	1.17	3.82	24.6	.637	4.11
1.375x3.25	"	4.47	"	320	2.25	1.98	12.8	.619	3.99
.625x4	1.588x10.16	2.5	16.	810	0.67	3.73	24.1	.451	2.91
.625x4	"	2.5	"	600	0.83	3.07	19.8	.512	3.30
.625x4	"	2.5	"	320	0.88	2.84	18.3	.888	5.74

* Average rate of cutting, 0.454 sq. inches (2.93 sq. cm.) per min. per 100 amperes.

Strengths of Welds.

Often the strength of the weld is of small consequence as it is simply a matter of filling up blow holes or equivalent imperfections, and even where strength of weld is involved, the metal to be welded usually has a very large factor of safety,

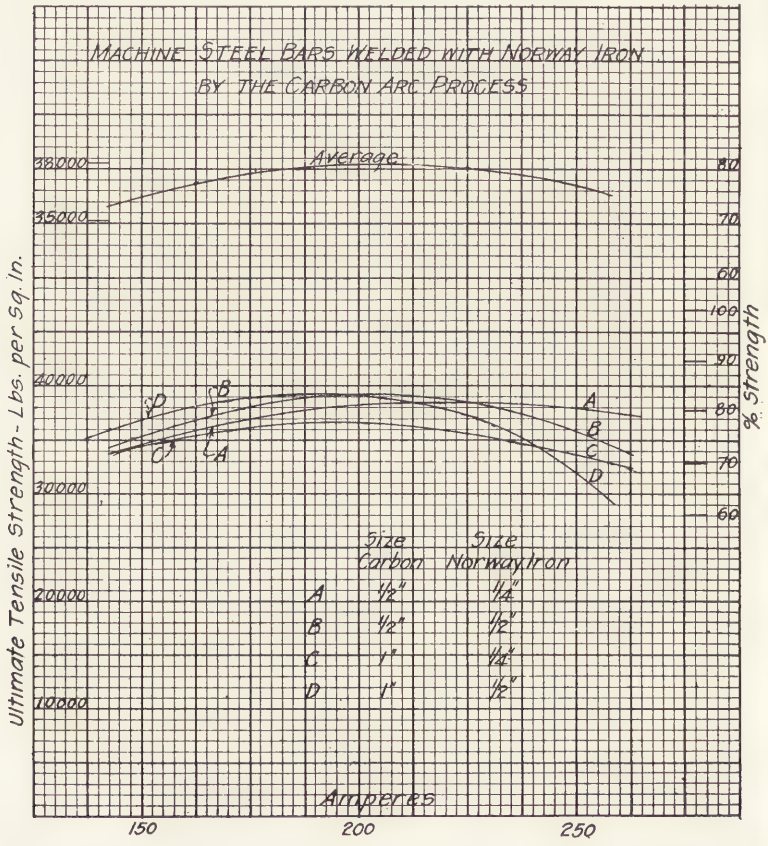


Fig. 8. Curves of Current and Strength. Machine Steel Welded with Carbon Electrode and using Norway Iron Filling.

so that even though the welded portion may not be equal in strength to the original material, it still will have a considerable margin of safety. Furthermore, the material at the weld can often be reinforced so that a strength equal to the original can thus be obtained.

With the carbon electrode process, the current will range from possibly 100 to 600 amperes or more, depending upon conditions; in cutting, the figures will usually run slightly higher. With the metal electrode process, the current for welding will range from 10 to 200 amperes.

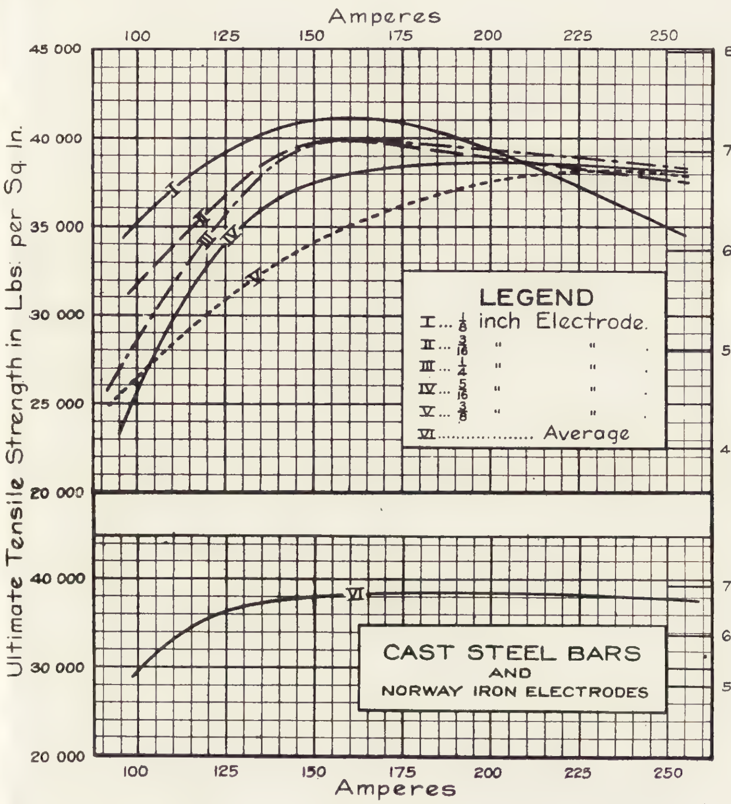


Fig. 9. Curves of Current and Strength. Cast Steel Welded with Norway Iron Electrodes.

In Figs. 7, 8, and 9, are shown results obtained by both processes (W. E. & M. Co.). It will be noted that in these curves there seem to be indicated certain best limits for current and size of electrode, and in the carbon arc process, the further fact that too rapid work as indicated by Fig. 8, curve D, is harmful. The converse of this, although not shown by

the curves, is likewise true. It may also be said that either process will give about the same strength of welds, but that in machine steel the ultimate strength will average approximately 80 per cent of the original, while in cast steel the ultimate strength of the welds will run 10 to 12 per cent lower.

Methods of Testing.

The samples were of open hearth machine steel and cast steel. The former were twelve inches long and one and one-quarter inches square; the latter twelve inches long and one and one-eighth inches square. The ends to be welded were chamfered, leaving a V-shaped opening to be filled with metal from the electrode.

In order to preserve the alignment of the two bars during welding, they were solidly clamped upon a copper strip resting on an iron table. All welding was done from above the bar, as would be the case in practice where the piece being welded could not be reached from both sides. The test bar chosen was such that the conditions for making a weld were worse than the average found in practice. A much stronger weld could be obtained by using double V'd bars and welding from both sides.

No flux, whatever, was used in any of the tests, and in every case, metal was added beyond the dimensions of the bar in order to insure solid metal after machining. After welding, the bars approximately twenty-four inches long, were planed to a cross-section one inch square. The weld line was barely discernible. Five sizes of Norway-iron electrodes—$\frac{1}{8}''$ (.3175 cm), $\frac{3}{16}''$ (.4763 cm), $\frac{1}{4}''$ (.635 cm), $\frac{5}{16}''$ (.7838 cm), and $\frac{3}{8}''$ (.9525 cm), were tried with currents ranging from 100 to 250 amperes and with the electrode negative in polarity. With each size, both for cast and for machine steel, ten samples were welded at each value of current, making a total of 300 samples. In addition, 20 samples were welded with the electrode positive in polarity.

The carbon electrode welds were 48 in number and were made with currents ranging from 150 to 250 amperes, using graphite rods from $\frac{1}{2}''$ (1.27 cm) to $1''$ (2.54 cm) in diameter and Norway-iron rods from $\frac{1}{4}''$ (.635 cm) to $\frac{1}{2}''$ (1.27 cm) in diameter as filling material. The best results were obtained

with ½″ (1.27 cm) electrodes and ½″ (1.27 cm) filling rods with 200 amperes.

The desired current was obtained by varying the excitation of the generator, as well as by the use of resistance in series with the arc.

Mechanical Testing.

The welded samples were tested in tension, the ultimate strength, yield point, elongation and contraction in area being determined. Tests of the machine and cast steel were upon bars 24″ (60.86 cm) long and one inch square; those upon Norway-iron filling rods were made with bars ⅜″ (.9525 cm) in diameter of the same composition as the electrodes.

Tables and Curves.

The appended tables give in detail the values for each condition and the curves previously referred to are drawn from the data in the tables.

Conditions for Metallic Electrode Welding.

Besides strength of weld, both with respect to the yield point and the ultimate breaking point of the original material, there are other considerations which must be taken into account. With large electrodes and small currents, welding proceeds slowly, the arc is harder to maintain and the heat developed is insufficient to make the metal flow readily.

Small electrodes and heavy currents are likewise undesirable, as here the metal flows too freely, the electrodes become white hot, molten drops of metal spatter from the weld and blisters form upon the metal. Though it might naturally be considered that the rapidity of welding would increase with the amount of current used, such is not the case beyond a certain limit. The fact that the added metal flows too rapidly and that fairly short electrodes must be used in the holders, makes welding with small electrodes and heavy currents slow and laborious.

Any combination of current and electrode which causes the metal to flow very readily, is useful only in those particular instances where the added metal cannot run away as soon as it is applied.

Potential Drop Across Arc.

The average potential drop across the metallic arc varied between 21 and 28 volts, increasing slightly with the current

and with the size of electrode; at times reaching as high as 35 volts or as low as 19. With the carbon electrode, the average varied from 40 to 50 volts, being nearer 40. This potential drop, as well as the current, depends upon the distance from the electrode to the metal being welded. It is manifestly impossible to maintain an exact distance and there is, moreover, a personal equation involved, some operators keeping the electrode nearer to the metal being welded than others.

Physical and Chemical Characteristics.

The fracture of the welded bars under test was in the center of the added metal of the weld and approximately at right angles to the bar, except in those cases where the heat was insufficient for a good weld and fracture occurred along the cleavage line between bar and added metal. The metal exposed by the fracture was crystalline in structure and very similar to cast iron in appearance. The ductility of the weld was much below that of the original steel or Norway iron, the maximum elongation and the contraction of any set of welded bars being 5.4%. These maximum values did not occur in the same set of samples, though in general the greater the elongation the greater the contraction in area. The yield point of the welded machine steel bars was slightly less than that of the unwelded steel or iron.

Three machine steel bars welded with metallic electrodes tested over 42,000 lbs. per sq. inch. These were all welded with $\frac{3}{16}''$ electrodes, but at currents of 125, 150 and 175 amperes respectively. The fact that in these cases the effect of the current was apparently *nil,* suggests that perhaps the results are to some considerable degree dependent upon the skill of the operator, and it might also be noted that the operator who made these welds is accustomed to use $\frac{3}{16}''$ electrodes for metallic arc welding.

The chemical analyses of the machine steel, cast steel and Norway iron used in these tests were as follows:

Contents	Machine Steel	Cast Steel	Norway Iron
C	0.10	0.10	0.10
Mn	0.39	0.71	0.075
S	0.024	0.052	0.012
P	0.010	0.05	0.028
Si	trace	0.37	trace

Direction of Current.

(a) Metallic Electrodes. Twenty bars were welded with the current reversed, i. e., with the electrode positive in polarity. Ten of these bars were welded with $\frac{3}{16}''$ electrodes and 175 amperes, and ten with $\frac{1}{4}''$ electrodes and 200 amperes. From the results obtained, it appears quite evident that it is more desirable to have the electrode negative since welds made under the same conditions, but with the electrode positive, averaged 11.25 per cent lower in tensile strength, 2.3 per cent lower in elongation and 2 per cent lower in contraction of area than with the electrode negative.

(b) Carbon Electrodes. The electrodes were in all cases made negative in polarity.

INCANDESCENT PROCESSES.

The incandescent or resistance processes of welding differ from the arc processes, not only in the method of obtaining the heating effect of the electric current, but in the further fact that pressure is also an essential factor. It is the introduction of resistance into the circuit such as is caused by a poor contact (Thomson process) or by a poor conductor (La Grange-Hoho process) that produces the necessary heat for welding.

La Grange-Hoho Process.

In the La Grange-Hoho process an electrolytic bath is required. The two pieces of metal to be welded are joined in parallel to the negative terminal of a direct-current circuit of 125 to 150 volts, a large plate of lead, carbon or other conductor immersed in the bath forming the positive terminal. The bath consists of a mixture by weight of 44 parts of carbonate of potash and 56 parts of borax dissolved in water to a specific gravity of 1.24. The passage of the current through the bath causes decomposition of the electrolyte, bubbles of hydrogen being deposited on the metals to be welded, thus introducing a gaseous resistance in the region of contact between the metals and the electrolyte, with the consequent heating of the metals to incandescence. When the metals reach the proper fusing temperature and while still continuing in the bath, they are forced together under heavy pressure, thus uniting, or they

may be withdrawn from the bath after reaching the fusing temperature and welded together under a hammer in the usual manner.

This process offers no advantage over the Thomson, or resistance process and the disadvantage of the bath is obvious. As far as it has been possible to ascertain the facts, the process is not used in this country at all.

Thomson Process.

In the Thomson process, the welding is effected in the secondary circuit of a single phase (25 to 60 cycle) transformer, which may have a capacity from 1 to 100 kw. or more, the primary being wound for any suitable voltage, usually 110 or 220, the secondary for ½ to 7 volts. The terminals of the secondary circuit generally consist of comparatively large jaws, frequently water-cooled, which clamp the metals to be welded. The power factor of a welding machine of this type will range from 50 to 85 per cent.

In the making of a weld, the ends of the two metals are butted together, first being filed flat if necessary, the lengths of each actually in the circuit being so adjusted as to make them equal in resistance, after which the primary circuit is closed. Current immediately flows through the metals, heating them very quickly at their point of contact to the temperature of fusion. They are then forced together by hand or automatically. The accompanying fin is easily eliminated either with a file after being taken from the welder or by means of an automatic hammer before being thus removed.

In certain phases of this process, as the spot welding of sheet metals and the equivalent, the metals to be welded are not clamped in jaws but are squeezed together between the electrodes of the secondary circuit.

Since the operation of welding is at all times under control, the weld may be made quickly or slowly and there is, therefore, no waste of current; furthermore, the heat is self-contained, that is, it is generated within the metals themselves and is, consequently, confined to the small portions between the jaws or electrodes.

From the preceding, it is quite evident that the quality of the welds made by this process should be uniformly higher

than those made by any of the arc processes or by the blacksmith, and it is, in fact, only exceeded by the electro-percussive process. It should, however, be equally evident that the Thomson process is best adapted for repetition work, while the arc processes are rather the reverse in this respect, so that as previously stated there is little advantageous overlapping of these processes.

As in the arc processes, the work is intermittent as far as actual welding time and current consumption are concerned, so that the efficiency of the apparatus in this single feature is

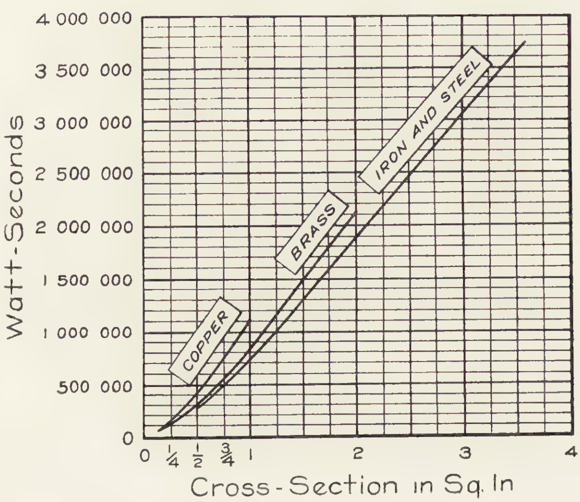


Fig. 10. Energy Curves, Thomson Process.

not of extreme importance compared with reliability, rapidity and continuity of operation. The energy consumption involved in the making of a weld, and omitting all reference to the apparatus itself and the efficiency of operating it, is dependent upon the thermal and the electrical conductivity of the metals, their shapes, lengths, cross-sections, temperatures of fusion and time consumed in welding. With reference to the curves shown on Fig. 10, Prof. Elihu Thomson states:

"It will be seen that the energy increases more rapidly than the section of the pieces, doubtless because the large

pieces take a longer time in welding, with the result of an increased loss by conduction of heat along the bars from the joint. If the time for welding could be made the same for various sections, it is probable that the energy required would be more nearly in direct proportion to the area of section for any given metal. This rule would, however, only hold approximately, as there is a greater relative loss of heat by radiation and convection into the air from the pieces of smaller sections''.

The Thomson process has a very great range as regards the metals as well as the shapes it is possible to weld.

The Thomson Electric Welding Company, who were the pioneers in this process and who have, therefore, had the greatest experience in this field, present the following as covering the metals and alloys which can be welded:

Metals. Wrought iron. Cast iron. Wrought copper. Lead. Tin. Zinc. Antimony. Cobalt. Nickel. Bismuth. Aluminum. Silver. Platinum. Gold (pure). Manganese.

Alloys. Various grades of tool steel. Various grades of mild steel. Steel castings. Chrome steel. Mushet steel. Stubs steel. Crescent steel. Bessemer steel. Nickel steel. Wrought brass. Gun metal. Brass Composition. Fuse metal. Type metal. Solder metal. German silver. Aluminum alloyed with iron. Aluminum brass. Aluminum bronze. Phosphor bronze. Silicon bronze. Coin silver. Various grades gold.

Combinations. Copper to brass. Copper to German silver. Copper to gold. Copper to silver. Brass to wrought iron. Tin to zinc. Tin to brass. Brass to German silver. Brass to platinum. Brass to tin. Brass to mild steel. Wrought iron to cast steel. Wrought iron to mild steel. Steel to platinum. Wrought iron to tool steel. Gold to German silver. Gold to silver. Gold to platinum. Silver to platinum. Wrought iron to Mushet steel. Wrought iron to Stubs steel. Wrought iron to Crescent steel. Wrought iron to cast brass. Wrought iron to German silver. Wrought iron to nickel. Tin to lead. Mild steel to tool steel. Nickel steel to machine steel.

Wires as small as .0225″ (.05725 cm) diameter, can be butt-welded, the strengths of the joints, assuming the work to have been properly done, being dependent upon the composition of the materials welded, in general varying from 75 per cent and upwards of the original stock, although certain investigators place the average as low as 63 per cent. For example, mild steel gives a very strong weld, while Bessemer steel, hav-

ing a greater percentage of sulphur and phosphorus, will not give such high results. Aluminum wires or rods can be successfully welded in the larger sizes; but, in the smaller sizes, the welds will be very unreliable, practically disintegrating if any attempt is made to work them as in rolling. This is probably due to the inability to rid the weld entirely of the oxide, which imperfection thus forms a greater percentage of the area of the weld in the smaller sizes, with consequent lower strength.

At times there will be a brittle zone at either side and a little distance away from the weld, caused by the excessive rate of dissipation of heat when the current is withdrawn. Where this constitutes a disadvantage, as in high carbon steel, brittleness may be eliminated by passing current a second time through the welded piece, sufficient to heat the parts to a red heat before removing them from the clamps, though it is rather better to loosen the clamps and move them further back so as to bring the brittle zones well within the circuit and further removed from the cooling influence of the clamps.

Machines for welding by this process are rather limited in their adaptability and can, therefore, of necessity follow no conventional lines in the details of their construction, though the principle involved is the same in all, as are the fundamental parts already briefly described.

Aside from the welding of wires, there is a multiplicity of other work, some large, some small, which can be advantageously performed by this process. Among such may be mentioned the welding of rings, buckles, frames for windows and the like, bars, rods, pipe, automobile parts, wheels, tires, cylinders, rails, bonds, chains, band-saws, wire fence, handles to blades, drills, high speed to machine steel for cutting tools, crank shafts, etc.

One of the most novel applications is the bonding of street car rails. As direct current is usually the only kind available, it must first be transformed to alternating current through the medium of a rotary converter. Instead of both portions of the clamps being of metal, as is usually the case, one part is of copper and one of carbon. About 2000 amperes at 5 volts applied for approximately 2 to 3 minutes, are required and the usual

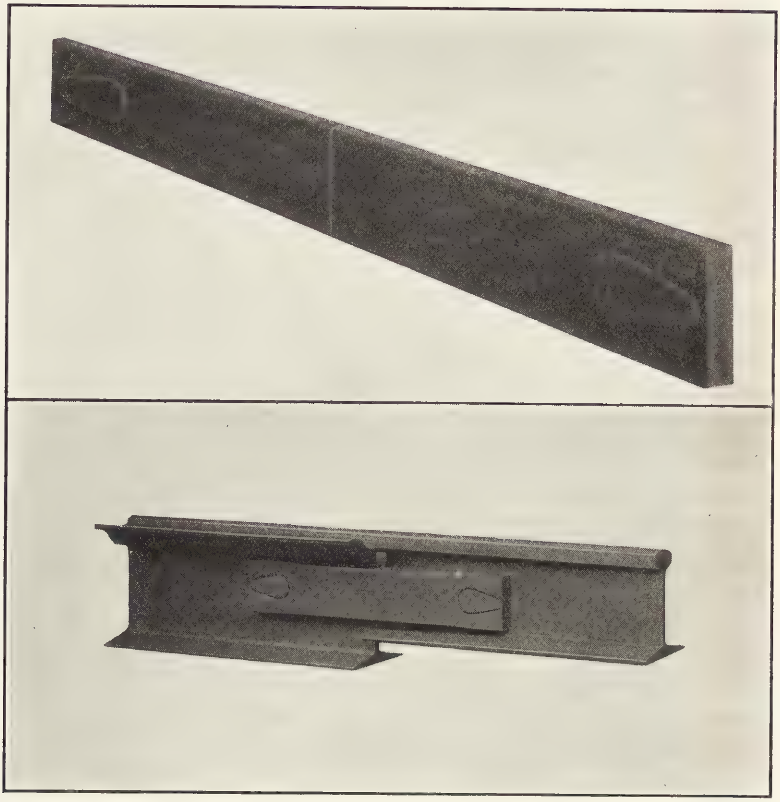


Fig. 11. Joint or Connecting Plate and Finished Weld Showing Rails of Different Section Joined.

operating force of three men can average 100 welds per day of 12 hours.

Very similar to this application is that of rail welding, but on a much larger scale. In this, about 30,000 amperes at 5 to 7 volts are applied for 2 to 3 minutes with a pressure of 4000 lbs. per sq. inch (282 kg. per sq. cm) on the weld. Fig. 11 shows the type of joint plate and finished weld. Two of these plates are necessary to each weld, one on either side of the rails being joined, and three welds are required to make a complete joint.

The joint plate is embossed at the ends, while at the center

a strap is fastened. These are all for the purpose of concentrating the heat during the welding operation, but the strap being an addition to the cross-section of the joint plates gives a stronger section of material where it is most needed, namely at the center of the plate and the ends of the rails. With an operating force of six men, 40 welds have been made per day of 12 hours. The use of expansion joints at suitable intervals now permits this method of joining to be used for rails above ground, as for example, on surface and elevated tracks, where formerly it was confined to rails buried so that their tops were flush with the surface of the ground.

The accompanying table, taken from the report for 1910 of the Supervising Engineers—Chicago Traction, gives the results of several years' experience with electrically-welded rails approximating 50,000 in number:

Summary Record of Electric-Welded Rail Joints, by Yearly Groups.

From Third Annual Report of the Board of Supervising Engineers, Chicago Traction. January 31st, 1910.

Year	No. joints welded	Total No. joints welded to Feb. 1.	Total failures		Failures 1907 welds		Failures 1908 welds		Failures 1909 welds	
			No.	% failures to joints welded	No.	% failures to joints welded 1907	No.	% failures to joints welded 1908	No.	% failures to joints welded 1909
1907	8,299		417	5.04	417	5.04				
1908	18,380	8,299	416	1.56	110	1.43	297	1.62		
1909	21,716	26,679	287	.59	92	1.11	91	.50	104	.48
Total to Feb. 1 1910	48,395	48,395	1120	2.31	628	7.57	388	2.12	104	.48

Spot and Projection Welding.

Later developments of the incandescent or resistance process of welding include what are known as spot, point, ridge, projection and button welding, etc., many of these serving as most desirable substitutes for riveting. Briefly, these embrace the welding of materials in spots or at points, the welding being accomplished either by simply laying the flat materials together and applying both heat and pressure through the medium of the electrodes, as in the case of thin sheets; or, by first forming points,

ridges or projections on the materials when thicker, then applying both heat and pressure; or, by laying the materials together when still thicker and placing between or on either side, a small flat metal button, then applying heat and pressure. Fig. 12 shows two views of sheets clamped between the electrodes of a spot-welding machine preparatory to being welded. In one of the views, the indentations have been made in one sheet only, in the other they have been made in both. Fig. 13 shows a variety of pieces which have been thus welded.

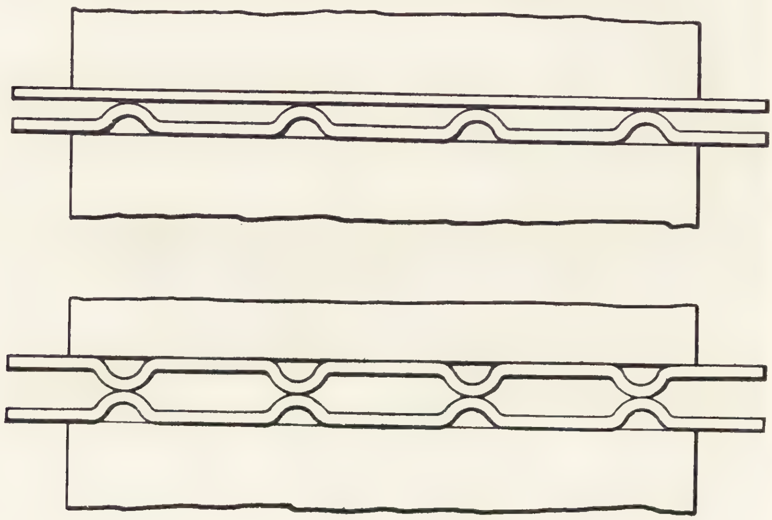


Fig. 12. Methods of Spot Welding.

A still further application of the incandescent process is in the lap welding of very thin ribbons, especially those of metals like nickel-chromium on which an oxide forms which is not readily removed. By the use of an embossing tool, such as a pair of pliers with faces like a file and between which the ribbons are squeezed before welding, many exceedingly small points are raised over the surfaces. The scale is thus broken down and good contact secured between the pieces of ribbon when subsequently placed together for welding. The welding may then be readily effected by placing the ribbons between electrodes, also fashioned like pliers, properly insulated and held in the hand during the operation.

Brazing and Soldering.

Electric brazing has received comparatively little attention, yet many materials can be effectively joined in this manner. A spot-welding machine can usually be employed with very little alteration, one or both terminals being of carbon or steel, as circumstances require. The "spelter" may for most purposes be either sheet brass or sheet silver from .005″ (.0127 cm) to .015 (.0381 cm) in thickness, and the flux, when it is found necessary to use any, may be a saturated solution of borax water. The heat, as in welding, is so perfectly controlled that there is no danger of burning the materials. Furthermore, a spot-welding machine, when it reaches its maximum limit in

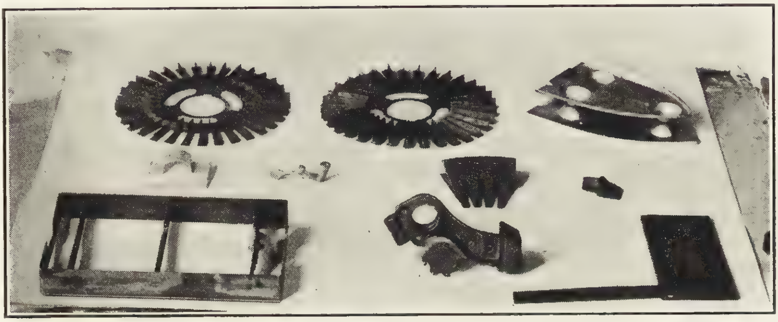


Fig. 13. A Variety of Articles made on a Spot Welding Machine.

welding, can do still larger work in brazing owing to the lower degree of heat required. When silver "spelter" is used, the joint is more flexible than a welded joint, and there is little danger from brittleness.

The time for brazing a joint will naturally be rather longer than that required for welding, and care must be taken where brazed joints lie extremely close to one another, that the heat from the joint being brazed, does not react on the joint previously brazed and undo it; or does not extend to the next joint to be brazed and heat it sufficiently to cause an oxide to form thus preventing brazing at all. These are, of course, the two extremes and are, ordinarily, not likely to occur; but where there is any possibility of such conditions, dampened asbestos will prevent the former and borax water the latter.

Electric soldering may be done in much the same manner as electric brazing, though it is perhaps more usual to butt together the metals to be soldered and after heating them to apply the solder by means of a soldering stick, rather than to use sheet "spelter" as in brazing.

Annealing.

The annealing of armor-plate was at one time accomplished by the resistance process, annealing being necessary to permit of subsequent drilling and cutting for port holes of turrets and the like. When used for this purpose, the secondary terminals of the welding apparatus are placed in contact with the armor plate at the desired spot. Current is turned on gradually until the correct temperature for annealing is attained, when it is then as gradually turned off—this being necessary to prevent a rehardening of the spot which would occur on sudden cooling. However, the advent of the oxy-hydrogen and oxy-acetylene processes of cutting has enabled material to be cut out in a more efficient manner.

Miscellaneous Applications.

Two additional uses, one the reverse of the other, have recently been found for the resistance process. Pickets for iron fences are admirably made by clamping a rod of the proper length between the jaws of a butt-welding machine, passing current through the small portion enclosed between the two sets of jaws; and, when heated almost to the melting point gradually separating the sets of jaws instead of suddenly forcing them together as in welding. The bar is separated into two portions, each with the heated end drawn out into a point. Rounds, squares and special sections respond equally well. The other use referred to is the forming of knobs, shoulders, etc., on bars, the operation being the same as just described except that the two sets of jaws are gradually forced towards each other to create the necessary amount of upsetting.

Costs.

Costs could be given, but would mean little on account of the several variables involved and for the further reason that certain manufacturers of welding apparatus sell their machines outright, while others simply lease them. The quantity of welds possible to be made in one day may range from 100 to

200 in heavy or difficult work, to several thousand in semi-automatic work. The set-up time is frequently greater than the welding time, so that the cost of the current is usually a small item compared with that of labor, both direct and indirect. The fact, however, of the increasing use of apparatus of the kind under discussion over a period of twenty years is the best evidence that the process is an advantageous one to employ for many purposes.

ELECTRO-PERCUSSIVE PROCESS.

As the electro-percussive method of welding is of more recent origin than any of the other methods, less is known of its ultimate possibilities, more especially with reference to its adaptability.

It will weld together any two metals, whether alike or unlike as to their composition, melting point, conductance, in fact, quite regardless of their characteristics, though such combinations as silver and tin, or aluminum and tin, iron or lead will of course not be permanent any more than they will be when welded by any other method, since their alloys disintegrate in time. Thus far, this method has been largely confined to the welding of small wires or the equivalent, aluminum to aluminum or copper, platinum to nickel or copper, thermo-couples, spring steel, etc.

The principle involved is that of percussive contact between two metals with a condenser discharge occurring at the instant of such contact. The various items involved include voltage, velocity and force of impact, capacity of condenser, resistance and inductance of circuit, these being, of course, properly proportioned to one another.

Fig. 14 is a schematic diagram of the method. The welder is much on the order of a miniature pile-driver, two grips for holding the metals to be welded being provided, one of these located at the base and corresponding to the pile, except that it is stationary, the other corresponding to the driver and dropping upon the first. G is a small direct current generator, preferably of 250 volts and about 1 kw. capacity, which is used to charge a condenser, (C) of the electrolytic type, through a high

resistance (R). Voltage control is secured through variation in the field of the generator, as well as by means of resistances R and R'. The welding apparatus proper W-W is connected to the condenser through an inductance L, long flexible leads being used to permit ready moving of the welder from place to place without the necessity of disturbing the auxiliaries. The terminals of the welder are bridged by the switch S, except in the actual making of a weld when the switch is opened; thus no potential difference exists between the terminals while inserting or removing wires from the welder.

The making of a weld is exceedingly simple. Either the metals to be welded, or if wires, their ends, are placed in the grips; the switch S is then opened, charging the condenser. A

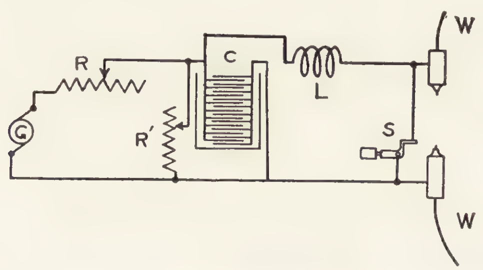


Fig. 14. Schematic Diagram of the Electro-Percussive Welder.

catch is finally released allowing the driver or hammer to fall, bringing the metals in so doing into percussive contact and making the weld which only requires the removal of the burr to complete it.

In explanation of the theory connected with the operation, it may be said that at the instant of contact, the condenser current is so heavy that the ends of the abutting metals are vaporized by the explosive discharge; and, due to the blow delivered by the falling mass, are forged together. The heat produced, though intense, is developed so quickly that it is confined to the extreme surfaces of the metals and there is, therefore, no opportunity for unequal heating with its possible deleterious effect on the welded materials. This generation of heat is dependent upon there being a certain resistance in circuit at the ends

of the metals being welded at the instant of their contact. It is, therefore, necessary to "V" them at right angles to each other with a pair of pliers.

The condenser current vaporizes the extremely small sections of the abutting metals and melts immediately thereafter the approaching surfaces of the two metals. This vaporization must of necessity result in a separation of the metals for an instant, not, however, due to any reversal in the direction of travel of the falling metal but simply because the rate of vaporization is greater than the velocity of the approaching surfaces. Upon the metals coming together again, the arc is extinguished and forging occurs.

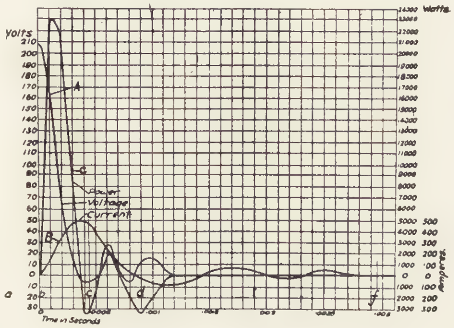


Fig. 15. Energy Curves of the Electro-Percussive Welding.

The weld takes the form of a sharp dividing line between the two metals, and on each side of it the original materials are found with no change in their physical properties, such as brittleness for example, either at or near the weld, as sometimes occurs in the resistance or incandescent method of welding. Hard drawn materials are not softened, soft materials are not hardened, nor is the temper of springs affected. Several theories have been advanced to account for these apparently irreconcilable statements. The almost instantaneous heating and cooling may not give time for molecular changes; or, if it does, the amount of material affected may be inappreciable. Further, with certain metals like hard steel, the heat generated is so quickly transferred into the shanks of the metals being welded, that the softened material is as quickly re-hardened.

In the case of hard copper, silver, etc., it may be that the softened material is again hardened by the cold forge after cooling.

Fig. 15 shows both current and voltage during the welding of a small wire [No. 18 B. & S. gauge (.1024 cm diam.)] while Fig. 16 shows the several stages in the course of a weld. It will be observed that the time required for the actual weld is but .0012 seconds, the total power consumption being 0.00000123 kilowatt hours. The oscillatory character of the power curve is due to the measurement of voltage having been made at points on the welder which included the two grips, and the oscillations are, therefore, due to the variations in the magnetic flux in them.

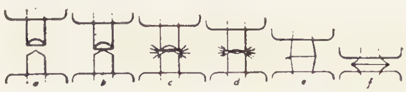


Fig. 16. Stages in the Process of the Electro-Percussive Weld.

Yield Point of Machine-steel Bars
Welded with Norway Iron Electrode.

Diam. of electrode inches / cm.	.125 (.3175)			.1875 (.4763)			.25 (.635)			.3125 (.7838)			.375 (.9525)		
Amperes.	Lbs. per sq. in.	Kilos per sq. cm.	% of Y.P. of unwelded material	Lbs. per sq. in.	Kilos per sq. cm.	% of Y.P. of unwelded material	Lbs. per sq. in.	Kilos per sq. cm.	% of Y.P. of unwelded material.	Lbs. per sq. in.	Kilos per sq. cm.	% of Y.P. of unwelded material	Lbs. per sq. in.	Kilos per sq. cm.	% of Y.P. of unwelded material
100	29600	2080	95.5	29400	2065	94.9	25600	1800	82.7	15900	1120	51.3	22000	1545	71.0
125	30300	2130	97.8	30300	2130	97.8	31100	2185	100.05	28900	2030	93.3	29700	2085	95.8
150	30400	2135	98.1	30400	2135	98.1	30400	2135	98.1	30600	2150	98.8	31800	2235	102.5
175	29500	2070	95.2	31100	2185	100.05	30400	2135	98.1	31000	2180	100.0	31900	2240	103.0
200	30800	2165	99.4	29800	2090	96.2	30600	2150	98.8	30700	2160	99.0	31800	2285	102.5
250	28400	1995	91.6	30500	2145	98.4	30500	2140	98.1	31700	2160	99.0	30700	2160	99.0

Ultimate Tensile Strength of Machine-steel Bars
Welded with Norway Iron Electrodes.

Diameter of electrode inches / cm.	.125 (.3175)			.1875 (.4763)			.25 (.635)			.3125 (.7838)			.375 (.9525)		
Amperes.	Lbs. per sq. in.	Kilos per sq. cm.	% of Ult. Ten. Str. of unwelded Mat'l	Lbs. per sq. in.	Kilos per sq. cm.	% of Ult. Ten. Str. of unwelded Mat'l	Lbs. per sq. in.	Kilos per sq. cm.	% of Ult. Ten. Str. of unwelded Mat'l	Lbs. per sq. in.	Kilos per sq. cm.	% of Ult. Ten. Str. of unwelded Mat'l	Lbs. per sq. in.	Kilos per sq. cm.	% of Ult. Ten. Str. of unwelded Mat'l
100	33500	2350	71.2	29400	2065	62.5	25600	1800	54.5	15900	1120	33.8	22000	1545	46.8
125	37400	2625	79.5	39400	2770	83.8	34800	2445	74.0	29500	2070	62.7	31700	2230	67.4
150	35000	2480	74.5	37500	2630	79.7	36700	2580	78.0	34400	2420	73.2	35000	2460	74.5
175	36000	2530	76.5	38700	2720	82.3	38300	2690	81.5	36800	2515	78.2	35500	2495	75.5
200	37600	2640	80.0	37300	2620	79.3	38100	2680	81.0	35100	2465	74.6	34000	2390	72.3
250	29600	2080	63.0	37800	2660	80.5	38600	2710	82.1	36100	2535	76.8	34300	2410	73.0

Percentage of Elongation in 2 inches (5.08 cm) and Contraction in Area at
Rupture in Machine-steel Bars Welded with Norway Iron Electrodes.

Diameter of electrode. inches / cm.	.125 (.3175)		.1875 (.4763)		.25 (.635)		.3125 (.7838)		.375 (.9525)	
Amperes.	Elongation %	Contraction %	Elongation %	Contraction %	Elongation %	Contraction %	Elongation %	Contraction %	Elongation %	Contraction %
100	1.77	1.28	1.61	1.26	1.48	0.65	0.93	0.29	1.84	0.27
125	3.42	1.89	4.43	3.36	2.86	1.67	2.40	1.60	2.33	1.84
150	2.63	1.87	3.71	3.11	3.87	2.35	3.35	2.45	2.48	2.60
175	3.09	1.59	4.37	3.28	5.13	3.03	5.02	3.12	3.57	3.20
200	3.85	2.61	4.88	3.71	5.41	4.36	4.22	3.48	3.33	3.22
250	2.71	1.88	4.77	4.09	4.65	4.83	4.97	3.93	4.32	2.84

Percentage Elongation in 2 inches (5.08 cm) of Unwelded Machine Steel 61.9
" " " " " (5.08 cm) " Unwelded Norway Iron 44.2

Percentage Contraction in area at rupture of, Unwelded Machine Steel 68.4
" " " " " " " " Unwelded Norway Iron 68.6

Effect of Reversal of Polarity on Machine-steel Bars
Welded with Norway Iron Electrodes.

	.1875 inch (.4763 cm) electrode 175 amperes.						.25 inch (.635 cm.) electrode 200 amperes					
	Electrode Negative.			Electrode Positive.			Electrode Negative.			Electrode Positive.		
	Lbs. per sq. in.	Kilos per sq. cm.	% of unwelded material	Lbs. per sq. in.	Kilos per sq. cm.	% of unwelded material	Lbs. per sq. in.	Kilos per sq. cm.	% of unwelded material	Lbs. per sq. in.	Kilos per sq. cm.	% of unwelded material
Yield point	31000	2185	100.0	30800	2165	99.4	30600	2180	98.8	29600	2080	95.5
Ultimate tensile strength	38700	2620	82.3	31500	2210	67.0	38100	2680	81.0	34700	2420	73.8
% Elongation in 2 in. (5.08 cm)	4.37			1.81			5.41			3.37		
% Contraction in area at rupture	3.28			1.68			4.36			1.95		

Yield Point of Machine-steel Bars Welded with the Carbon
Electrode and using Norway Iron Filling Material.

Amperes		150			200			250		
Electrode size	Filling Rod size	Lbs. per sq. in.	Kilos sq. cm.	% Y.P. U. Mtl.	Lbs. per sq. in.	Kilos sq. cm.	% Y.P. U. Mtl.	Lbs. per sq. in.	Kilos sq. cm.	% Y.P. U. Mtl.
0.5 in. (1.27 cm)	0.25 in. (.635 cm)	29700	2085	95.8	29900	2100	96.5	30400	2135	98.1
0.5 in. (1.27 cm)	0.5 in. (1.27 cm)	30400	2135	98.1	31500	2215	101.5	30200	2125	97.4
1.0 in. (2.54 cm)	0.25 in. (.635 cm)	30400	2135	98.1	29800	2090	96.2	30000	2110	96.7
1.0 in. (2.54 cm)	0.5 in. (1.27 cm)	29700	2085	95.8	30300	2130	97.8	30600	2150	98.8

Ultimate Tensile Strength of Machine-steel Bars Welded with the
Carbon Electrode and using Norway Iron Filling Material.

Amperes		150			200			250		
Electrode size	Filling Rod size	Lbs. per sq. in.	Kilos sq. cm.	% Ult.T.S U. Mtl.	Lbs. per sq. in.	Kilos sq. cm.	% Ult T.S U Mtl.	Lbs. per sq. in.	Kilos sq. cm.	% Ult.T. S.U. Mtl.
0.5 in. (1.27 cm)	0.25 in. (.635 cm)	34500	2410	73.4	38300	2690	81.5	37900	2665	80.6
0.5 in. (1.27 cm)	0.5 in. (1.27 cm)	35300	2480	75.0	39300	2760	83.6	36000	2530	76.6
1.0 in. (2.54 cm)	0.25 in. (.635 cm)	37000	2600	78.7	39200	2755	83.4	32100	2255	68.3
1.0 in. (2.54 cm)	0.5 in. (1.27 cm)	34400	2420	73.2	36500	2565	77.6	33600	2360	71.5

Percentage Elongation in 2 inches (5.08 cm) and Contraction in Area at Rupture of Machine Steel Bars Welded with the Carbon Electrode and Using Norway Iron Filling Material.

Amperes		150		200		250	
Electrode size.	Filling Rod size.	Elongation %	Contraction %	Elongation %	Contraction %	Elongation %	Contraction %
0.5 inch (1.27 cm)	0.25 inch (.635 cm)	5.2	5.4	5.0	6.4	3.4	3.7
0.5 inch (1.27 cm)	0.5 inch (1.27 cm)	2.5	2.5	4.4	6.0	3.8	4.2
1.0 inch (2.54 cm)	0.25 inch (.635 cm)	4.5	6.0	5.6	7.1	2.0	2.4
1.0 inch (2.54 cm)	1.5 inch (1.27 cm)	3.2	4.2	4.0	5.5	2.5	3.3

Percentage Elongation in 2" (5.04 cm) of Unwelded Machine Steel 61.9
" " " 2" (5.04 cm) " Norway Iron 44.2

Percentage Contraction in area at rupture in Unwelded Machine Steel 68.4
" " " " " " " Norway Iron 68.6

Yield Point of Cast-steel Bars Welded with Norway Iron Electrodes. The Ultimate Tensile Strength of Cast-steel Bars Welded with Norway Iron Electrodes was Practically Coincident with the Yield Point.

Diameter electrode inches cm.	.125 (.3175)			.1875 (.4763)			.25 (.635)			.3125 (.7848)			.375 (.9525)		
Amperes.	Lbs. per sq. in.	Kilos per sq. cm.	% Y.P. Un-welded Mat'l	Lbs. per sq. in.	Kilos per sq. cm.	% Y.P. Un-welded Mat'l	Lbs. per sq. in.	Kilos per sq. cm.	% Y.P. Un-welded Mat'l	Lbs. per sq. in.	Kilos per sq. cm.	% Y.P. Un-welded Mat'l	Lbs. per sq. in.	Kilos per sq. cm.	% Y.P. Un-welded Mat'l
100	37600	2640	66.8	32100	2250	57.1	26400	1855	47.0	24400	1715	43.4	26200	1840	46.6
125	40300	2830	71.7	36400	2555	64.7	37800	2650	67.2	36600	2570	65.1	31000	2175	55.2
150	39900	2800	71.0	39900	2800	71.0	38600	2710	68.6	38600	2710	68.7	32900	2310	58.5
175	49900	2875	72.7	39400	2765	70.0	40700	2860	72.4	36800	2585	65.4	34900	2450	62.0
200	39400	2765	70.0	38500	2700	68.5	38200	2680	67.9	37700	2645	67.0	38600	2710	68.6
250	35000	2455	62.2	38000	2665	67.6	39800	2790	70.8	38900	2730	69.2	37700	2645	67.0

Percentage Elongation in 2 inches (5.04 cm) and Contraction in Area at Rupture in Cast-Steel Bars Welded with Norway Iron Electrodes.

Diameter electrode inches cm.	.125 (.3175)		.1875 (.4763)		.25 (.635)		.3125 (.7848)		.375 (.9525)	
Amperes.	Elongation %	Contraction %	Elongation %	Contraction %	Elongation %	Contraction %	Elongation %	Contraction %	Elongation %	Contraction %
100	2.4	2.6	2.37	1.81	1.46	0.96	1.56	1.29	2.03	1.55
125	2.2	4.1	2.61	2.72	2.8	2.8	2.4	3.1	1.81	1.84
150	2.2	3.9	2.73	3.63	3.2	3.2	3.3	3.8	2.2	2.4
175	2.3	3.3	2.5	4.7	4.0	4.4	2.83	3.59	2.8	3.7
200	2.3	3.04	2.6	5.4	3.8	4.0	2.82	4.41	3.3	4.5
250	2.06	2.82	2.26	3.57	4.0	5.2	3.0	3.9	2.5	3.5

Percentage Elongation in 2" (5.04 cm) of Unwelded Cast Steel 6.55
" " " 2" (5.04 cm) of Unwelded Norway Iron 44.2

Percentage Contraction in area at rupture of Unwelded Cast Steel 7.4
" " " " " " " Norway Iron 68.6

DISCUSSION

Mr. Weber. **Mr. F. D. Weber,*** Assoc. A. I. E. E., stated that he knew of a steel cabinet box manufacturer who tried to spot-weld the hinges onto the box. This was abandoned because 25% of the hinges would break off during installation. This seems to be due to the jarring occurring during handling.

Mr. Davis. **Mr. W. J. Davis, Jr.,†** Mem. A. I. E. E., suggested that, apparently, some flux ought to be used in spot-welding to overcome the oxide film.

* Portland, Oregon.

† Engr., General Electric Co., San Francisco, Calif.

Paper No. 137

THE APPLICATION OF ELECTRICITY TO THE HEATING OF METALS.

By

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Pittsburgh, Pa., U. S. A.

This paper covers the recent developments, present status and limitations in the application of electricity to the heating of metals for the purposes of annealing, hardening or other heat treatments. No attempt is made to give the complete historical development of the subject. Only such historical material as is necessary to make the present discussion and development clear is presented. Furnaces employing electricity as a source of heat may be roughly classified into laboratory and commercial divisions. A brief discussion is given of different types of furnaces employed in laboratory work and an outline of the application of these furnaces to commercial service, where such application has been made.

The different types of furnaces, whether for laboratory or for commercial use, may be classified according to the methods employed to transform the electrical energy into heat in the material.

These methods are:

1. By passing the current through the metal to be treated, so that the metal forms a part of the circuit.

2. By passing the current through a resistance material, the heat thus produced being radiated and conducted to the metal.

3. By surrounding the metal with an alternating-current circuit, so that eddy currents are produced in the metal, these currents generating the necessary heat.

These three methods are radically different, in that the metal is heated in a different way in each case.

First Method: In this process the resistance of the material to the passage of the current causes the liberation of the heat uniformly throughout the material, provided the cross-section be uniform and the surface have uniform radiation.

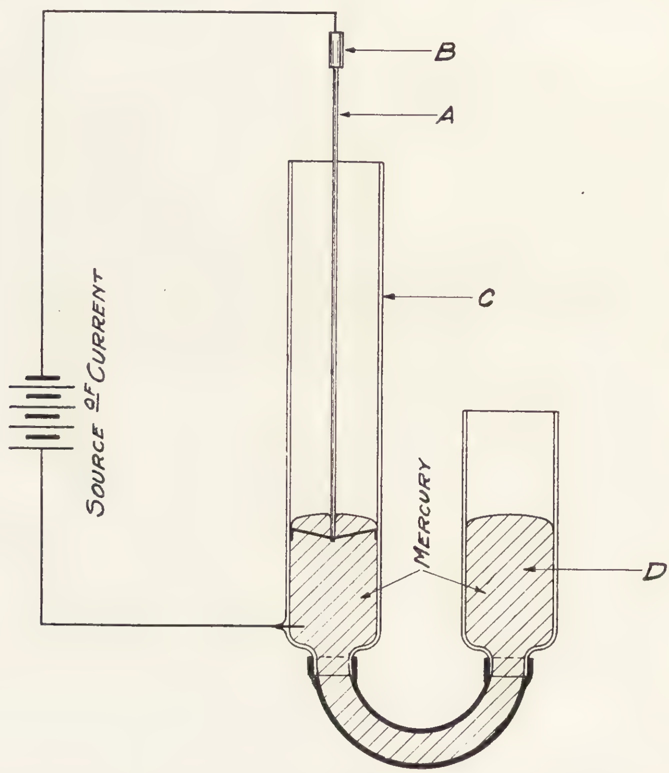


Fig. 1. Apparatus for Annealing and Hardening Small Iron and Steel Wire.

The process is limited in application by the size of the pieces which can be conveniently heated and to which a current can be conducted by means of proper terminals.

An apparatus of this type has been used to some extent for the annealing and hardening of small iron and steel wire.

The wire which is to be treated is shown at "A" (Fig. 1),

clamped to one terminal of a source of electricity; the other end is clamped below the mercury in the glass tube "C" (Fig. 1). The current is applied until the wire has attained the desired temperature, when the mercury cup "D" is suddenly raised, causing the mercury to rise in the tube C, thus cooling the wire, and at the same time shunting the current through the mercury. The current is then cut off and the wire removed.

The resistance of the wire should be small in comparison to that of the rest of the circuit, so that the current will not increase appreciably as the mercury rises; otherwise, unequal heating will result. The consistent results obtained in this way are due to the fact that the metal is heated uniformly to any

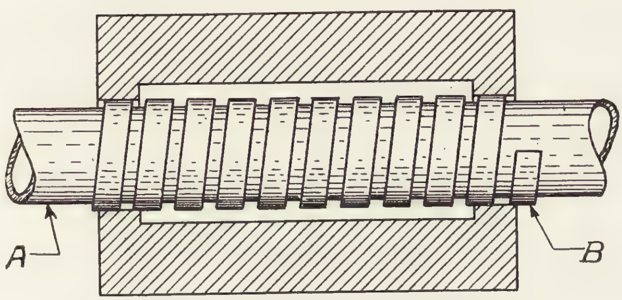


Fig. 2. Section of Heræus Furnace.

desired temperature, and also to the fact that the whole of the material is at the same temperature when cooled.

This method of heating metals has had very few commercial applications, although for certain classes of work it should prove useful.

Rateau* discussed the use of the electric current for heating the steel wire that forms the spring of the magazine of the French military rifle, 1886 pattern. The wire, 3 meters long by 0.07 mm. thick, is wound on a mandrel, forming a helix of 75 to 80 turns. It is held in this form between electro-magnets 1 meter apart, and 13 to 14 amperes are applied. When sufficiently heated, the current is cut off, causing the wire to fall into a tank of water. One workman can treat 2400 springs in

* Comptes Rendus Mensuels de la Sociètè de L'Industrie. Minerale 1891 O. 122-133.

nine hours. The cost was one quarter of that of the charcoal heating formerly used.

Second Method: One of the earliest and most useful types of electric furnaces is that due to the firm of Heræus. It consists of a tube, A, Fig. 2, wound in its middle portion with an electric resistor, B. The ends of the tube are cooled by air or else by a copper coil through which water flows. The tube may be of porcelain, in which case a ribbon of metal may be wound on it. These tubes are porous and cannot be used for a vacuum furnace. Glazed German porcelain may be used up to 1180°C. and a vacuum maintained. For higher temperatures, a nickel tube may be employed. The metallic winding is usually of platinum, nickel, nichrome, tungsten, etc. These furnaces are advantageous where a constant temperature is desired. They are easily constructed and consequently have been extensively applied.

One of the more recent developments is the Arsen* vacuum furnace (Fig. 3). The general design of the Arsen furnace comprises a heater of such shape that it almost entirely encloses the object to be heated. The heaters in the various types of furnaces differ somewhat, according to the size of the furnace and the use to which it is to be put. In one case, the heater is a graphite helix, in an upright position; and in another, it is composed of four grids, made by sawing graphite slabs.

The vacuum chamber is of steel. All joints are made tight by lead gaskets. The electrode joints have to be made so that they are air tight, electrically insulated, and not liable to deterioration by heat.

The radiation screen is a device for diminishing the amount of heat lost by direct radiation from the heater, and thus increases the efficiency of the furnace. This is shown by the fact that the temperature vs. energy curve is approximately a semicubical parabola, whereas, without the radiation screen, the curve would follow the Stefan-Boltsmann fourth-power law, like an incandescent lamp.

In the small, vertical type of furnace, the radiation screen is a rectangular graphite box filled with graphite powder, which is a poor conductor of heat.

* General Electric Company Bulletin, No. 4898 D. April, 1914.

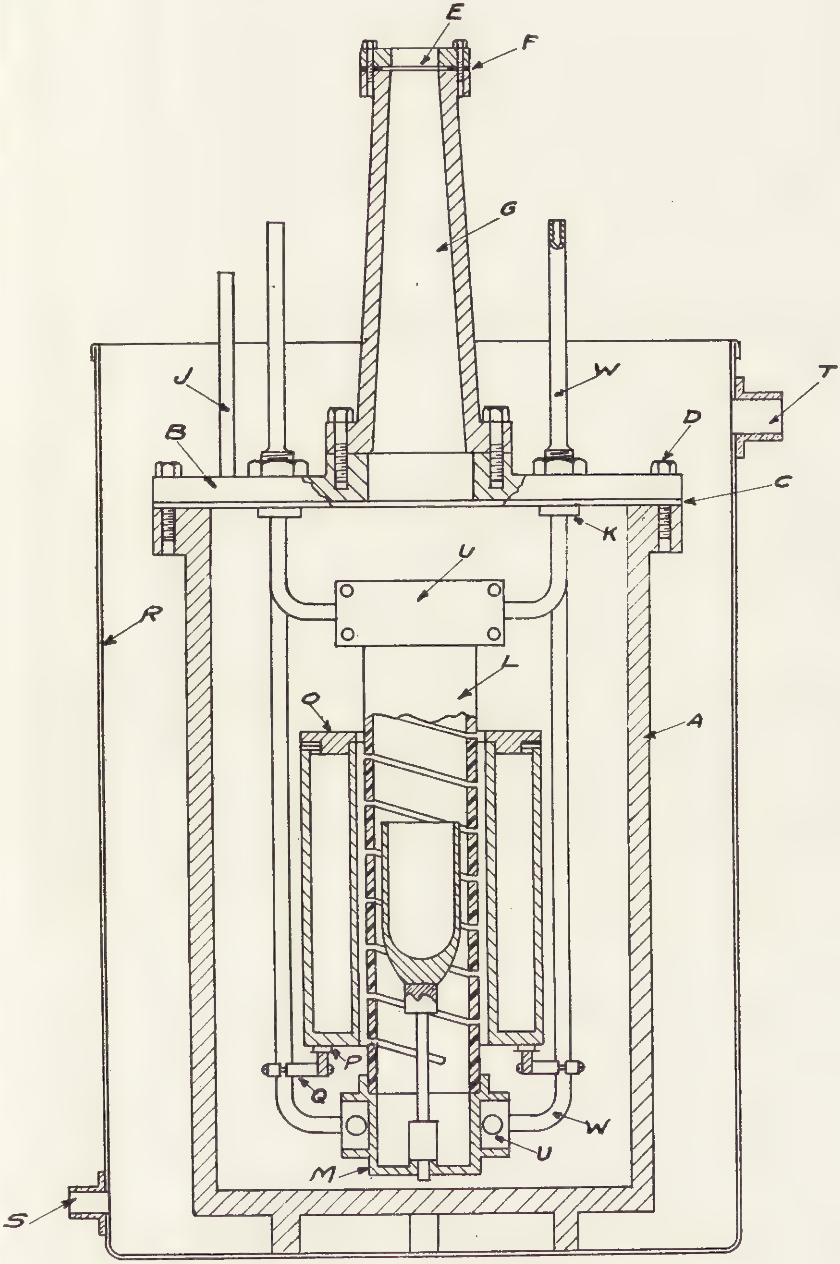


Fig. 3. Arsen Furnace.

The temperature can be quickly brought to any desired point, as determined by the calibration curve, and maintained constant for long periods, while the behavior of the article being heated may be observed through the mica window at the top. The range of temperature extends to 3100°C., using a maximum of 15 kw., but most experiments do not require a higher temperature than 2500°C., which can be obtained with 10 kw.

This type of furnace is especially useful for small scale experiments that can be performed in crucibles 1½ in. in diameter and 4 in. high. Of the various uses which naturally suggest themselves, I mention the following:

Preparation of metals, alloys, carbides, silicides, and other compounds.

Determination of the melting points of metals, alloys, glazes, slags, refractories, etc., by an optical pyrometer, or by reference to the furnace calibration curve.

Calibration of optical pyrometers.

Distillation of refractory substances for separation or purification.

Study of the equilibrium in reactions depending upon the pressure of gaseous phase.

Many reactions can be studied quantitatively with accurately weighed quantities.

For chemical analysis, annealing, enameling, ceramic experiments and ignitions of all kinds, where a temperature of 1000°C. is desired, the muffle furnace, a modification of the Heræus furnace, is the best type.

In most of these furnaces the heating resistance is completely imbedded in the walls of the muffle, which is thereby fairly uniformly heated. The maximum temperature for which they can be used is 1000°C., and regulation of the temperature between 800° and 1000°C. is effected by means of a rheostat.

One type of the muffle furnace, Fig. 4, introduces a useful feature in the form of a device which serves both as cut-out and current indicator. This consists of a gold wire loop, which forms part of the heating circuit and is visible through a mica window in one side of the muffle covering. When starting the furnace, the resistance should be adjusted until the gold wire

just begins to glow. After a little while, the loop will indicate a drop in the current, and more resistance may be switched out until the wire begins to glow again. As the temperature rises, the loop will become heated by the furnace, and the current necessary to keep it at red heat will gradually decrease. The appearance of the wire loop, accordingly, serves for regulating the current to the heat of the furnace. All that is necessary is

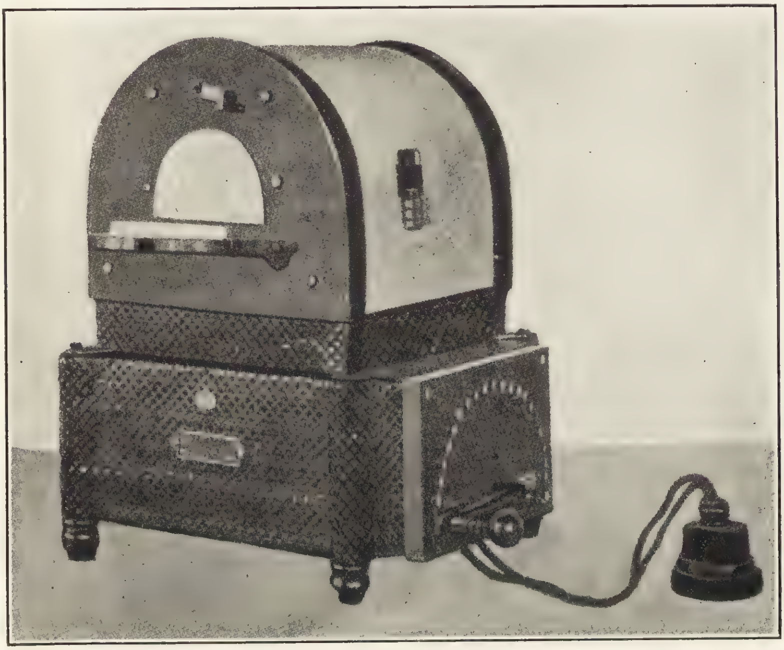


Fig. 4. Muffle Furnace.

to adjust the rheostat from time to time to maintain the loop at red heat, an operation which may be left to even an unskilled workman, after one or two lessons. For many purposes, this device renders the use of a pyrometer unnecessary.

The type of furnace due to Borchers (Fig. 5) consists of a carbon rod placed between large electrodes. Current flowing through the carbon rod heats it, and the substance to be heated surrounds the rod.

Current* conducted thru a carbon or graphite tube.

Tube	
Graphite	295 amperes, 8.2 volts.
28 x 1.5 x 2 cm.	Nickel melted in 26 min.
Carbon	140 amperes, 7.7 volts.
27 x 2 x 1.5 cm.	Nickel melted in 17 min.
Carbon	235 amperes, 16.4 volts.
27 x 2 x 1.5 cm.	Nickel melted in 5.5 min.
Carbon	600 amperes, 8.6 volts.
60 x 1.2 x 6.7 cm.	1200° C. in 30 min.
	850 amperes, 13 volts.
	Nickel melted in 12 min.

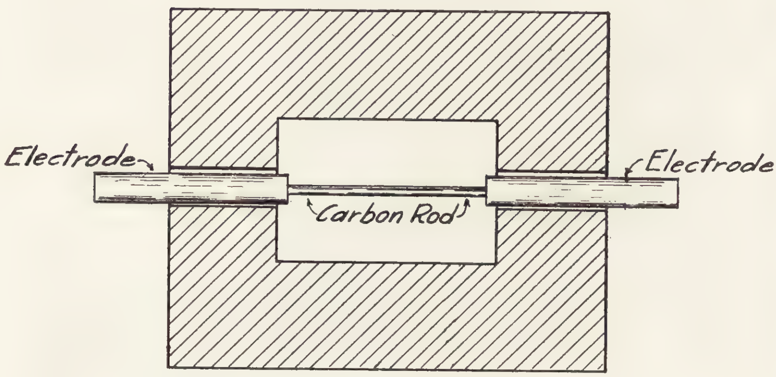


Fig. 5. **Section of Borchers' Furnace.**

The application of this type of furnace is limited by the temperature to which the graphite and carbon can be raised without oxidation.

A furnace by Watts † consists of a rectangular brick box, into which the crucibles are set, crushed carbon shovelled in and packed around them and the current turned on until the desired temperature is reached. Outside dimensions: length,

* "Electrically Heated Carbon Tube Furnace", R. S. Hutton and W. H. Patterson, Trans. Faraday Society, Vol. 1, 1905, p. 187.

† "An Electric Furnace for Heating Crucibles", Oliver P. Watts, Ph. D.

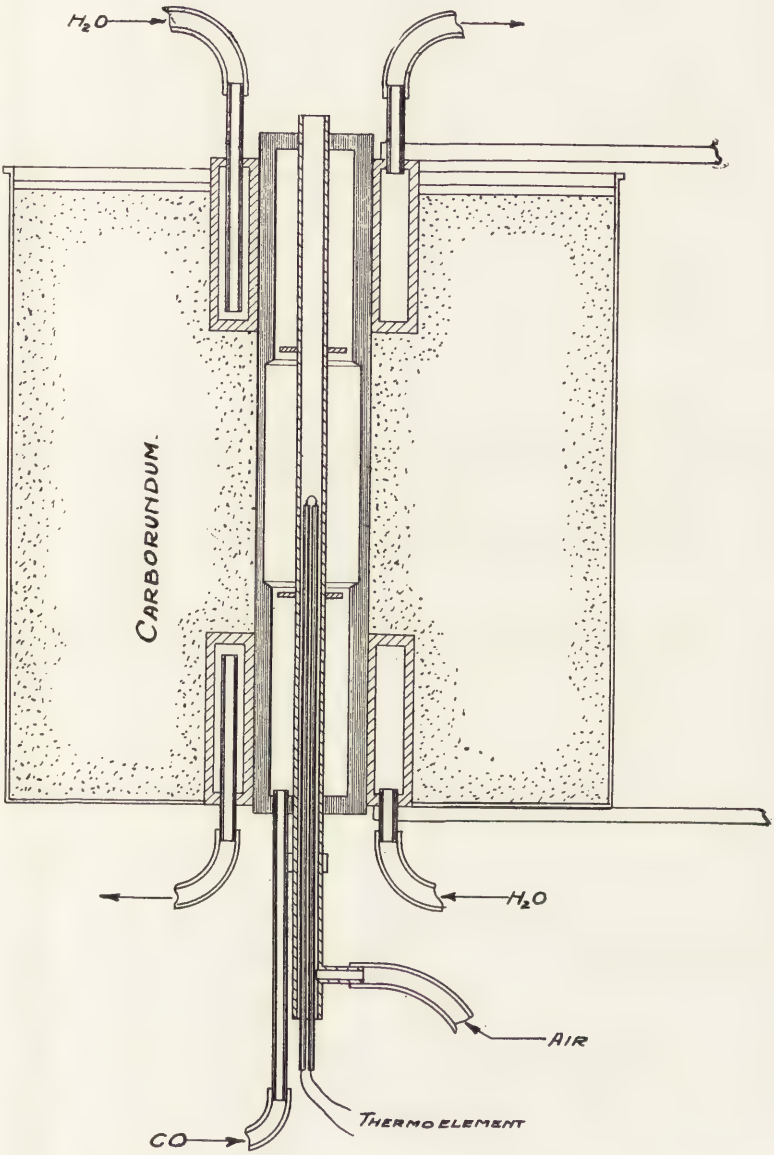
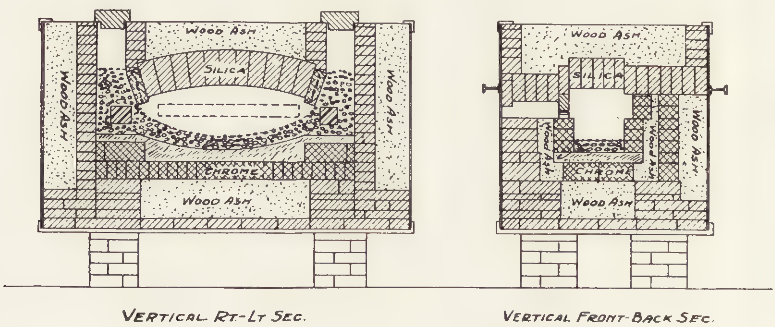


Fig. 6. Sosman's Carbon Furnace.

54″; width, 28″; depth, 26″. Inside dimensions: length, 40″; width, 12½″; depth, 9″. This furnace holds 27 crucibles 3″ in diameter and 7″ high and is used to melt iron and other metals.

The Sosman carbon furnace (Fig. 6) is a modification of this type, in which powdered carbon or carborundum surrounds a chamber containing the substance to be heated. High and uniform temperatures have been claimed for this furnace, but its application in this form is limited to small laboratory practice; however, a modification used by Bailey has proved of commercial importance.

The Bailey* furnace (Figs. 7 and 8) is of the resistance type and consists essentially of two carbon electrodes sepa-



Figs. 7 and 8. Bailey Furnace.

rated by an intermediate resistance body of a carbonaceous composition, in which the heat is generated.

The metal to be heated is placed in the space immediately above the resistance material and directly under the roof of the furnace, ledges at the rear and at the opening supporting the bars or billets, as the case may be. The electrodes enter through the rear wall and are placed slightly convergent, so that the path of the electric current will be shorter from electrode to electrode at the front of the furnace than at the back. This arrangement compensates for the greater cooling in the front, on account of the opening and the charging of cold material. The electrodes entering the furnace from the rear pre-

* "An Electric Furnace for Heating of Bars and Billets", Thaddeus F. B. Bailey, Trans. of the Amer. Electro-Chem. Soc.

sent comparatively large contact surfaces to the resistance material, without the use of special electrode sections.

The electrodes are also placed above the resistance materials. This prevents the current from taking a lower course when the furnace is charged with cold metal. The resistance material is crushed coke which will pass over a 0.250″ iron ring and through a 0.37″ (9 mm.) ring. This requires a voltage of 200 for a 40 kw. input. The furnace is controlled by means of a regulating transformer and controller. The thermal efficiency varies from 33 to 65%, with heating capacities of from 120 lbs. to 1000 lbs. per hour. Temperatures of about 3200°F. (1765°C.) are obtained. This furnace is used for treating forgings, etc.

The principal advantages of the electric furnace are its high thermal efficiency, non-oxidizing atmosphere and freedom from soot, smoke, and contamination of gases due to combustion.

Used Grecian Magnitite lining, Temp. ..	3200° F.	1760° C.
Temperature of iron cut at charging......	2615° F.	1435° C.
Temperature of iron cut at withdrawing	2600° F.	1426° C.
Amperage	1150 amperes	
Voltage on furnace........................	60 volts.	
Power factor	0.99	
Indicated kw.	69 kw.	
Metal—8 bars, 1½″ square x 18″ long. ..	92 lbs.	41.7 kg.
Time in furnace	20 min.	
Temperature of metal at charge..............	60° F.	14° C.
Temperature of metal at withdrawing....	2360° F.	1239° C.
Kilowatts consumed in heating................	23 kw.	
Pounds of metal per kw.	4 lbs.	
Kilowatts per ton	500 kw.	
Capacity of furnace per hour..................	276 lbs.	

''Further Development of the Electric Furnace for Heating Bars and Billets'', Thaddeus Bailey, Trans. Am. Elec.-Chem. Society, Vol. XXI, 1912, p. 49. Proceedings, Engr. Soc. of Western Penna., April 1915, Vol. 31, No. 4.

A resistance type of furnace especially designed for hardening consists of a bath of molten metallic salts or mixtures, which are heated by passing the current through them. The current is led into the bath by means of electrodes, and as soon as the salts become molten, they penetrate all parts of the bath.

The metal is immersed in the bath and allowed to remain until it attains the temperature of the bath. This temperature will, of course, depend upon the kind of salts used.

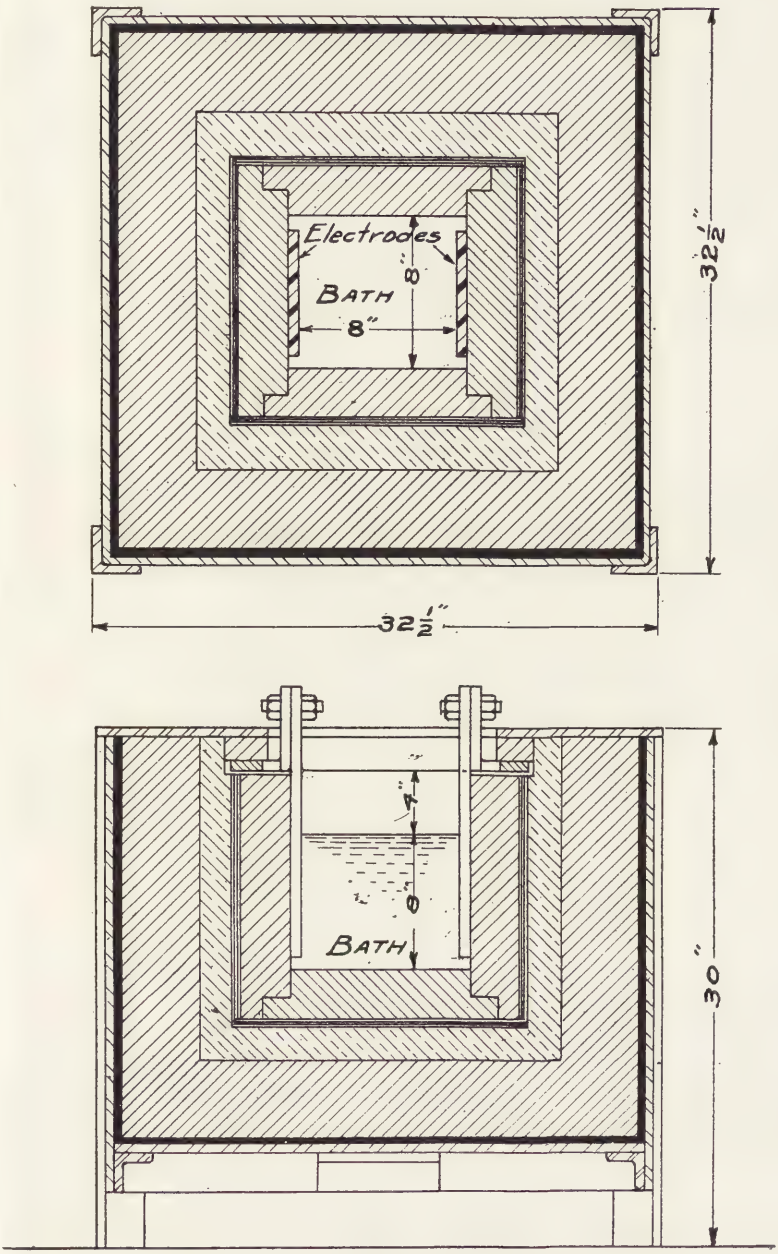
One model of this furnace* which has attained considerable commercial use is constructed as follows:

The crucible, or container for the bath, is made up of fire-bricks, which are surrounded by heat insulating material and supported in a sheet-iron case, as shown in Figs. 9 and 10. Two iron electrodes, located on opposite sides of the crucible, direct the current through the bath. A suitable regulator, usually of the switch type, is used. By means of this regulator, the available voltage is stepped down to that required by the furnace, and means are also provided for regulating the power and, consequently, the temperature of the bath.

The kind of salt used in these furnaces depends upon the temperature desired. For hardening high-speed steel, barium chloride should be used; while for carbon steel, a mixture of barium chloride and potassium chloride is recommended. For still lower temperatures, potassium chloride only—common salt, saltpeter, etc.—may be employed; this latter salt being suitable for as low a temperature as 350 deg. C.

These salts are non-conductors of current when cold and become conductors of the second class when molten. Means are therefore provided for obtaining a channel of molten conducting salt between the two electrodes, as illustrated in Fig. 11. With a carbon rod pressed between one of the main electrodes and the auxiliary electrode, power is applied and current flows through the carbon, generating heat therein and causing the surrounding salt to melt. The auxiliary electrode may then be moved slowly toward the main electrode, to which it is connected, leaving a channel of liquid salt between the two main electrodes. With the power left on, the bath will soon become liquid throughout, and any desired temperature, including the very highest used for hardening, can be obtained with precision by adjusting the power through the regulator. The time required for melting all the salt varies from one to two hours, depending upon the size of the bath and the power applied.

* "Electric Hardening Furnace", M. Unger, Gen. Elect. Review, Vol. XVI, No. 3, p. 158.



Figs. 9 and 10. Electric Hardening Furnace.

The temperature of the bath can be accurately measured with a pyrometer, the "fire end" of which is immersed in the bath.

The temperature of the bath is absolutely uniform throughout, due to the pronounced circulation. The circulation is caused, mainly, by the electromagnetic forces set up by the heavy current, and, in this respect, these furnaces have a great advantage over all other "wet heat" furnaces.

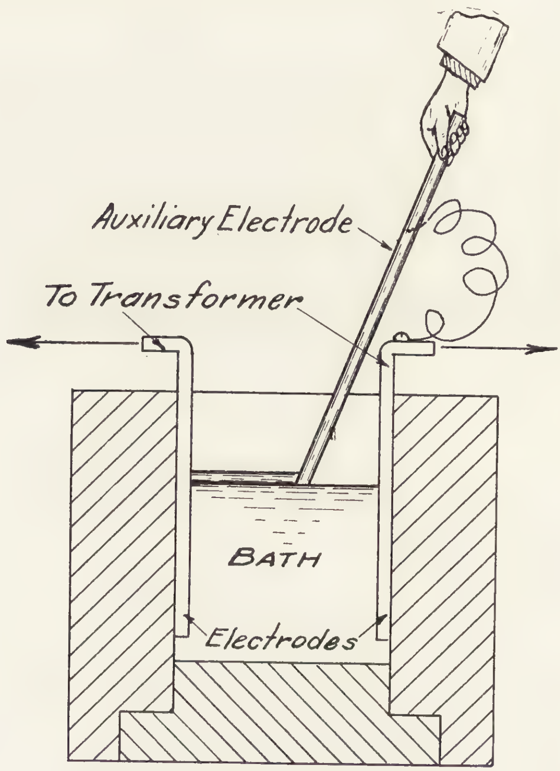


Fig. 11. Method of Starting Furnace.

When a tool is placed in the bath, it will be noted that the surrounding salt solidifies, say to a thickness of $\frac{1}{32}''$, and this blanket of salt will melt slowly. This is of great advantage in reducing the shock from sudden heating, the solid salt being a poor conductor of heat. When the tool has finally attained the temperature of the bath and is removed, it will be noted that it is covered with a thin film of salt, which protects against oxida-

tion; but as soon as the steel strikes the cooling medium, the salt chips off, leaving a clean surface. The salt has absolutely no chemical effect upon carbon steel; and if certain precautions are taken, there is no difficulty with high-speed steel. Blistering or pitting of the surface of the tools has never been observed.

This furnace, it is claimed, answers the following conditions, which are evidently necessary in any hardening furnace:

1. It must be possible to produce and maintain constant any temperature that may be required for any particular steel.
2. It must be possible to ascertain practically the exact temperature of the steel.
3. The heating must be uniform throughout, and overheating and burning of edges and sharp points of the tools should be made impossible.
4. The heating must not be too sudden, so as to avoid internal stresses, which may cause warping and cracking of the steel.
5. During heating, the steel must be protected from oxidation as much as possible.
6. The furnace must be efficient and easy to operate.

The crucibles will last six months.

The following tables show the results of experiments made to determine the comparative costs of hardening milling cutters in gas and electric furnaces: *

Gas.

12,300 cu. ft. of gas	£2	3s	3d
Air blast	0	5	0
Labor, 50 hours	1	15	5
	£4	3s	8d

Electric.

Electric furnace, 200 kw. hours	£1	0s	0d
Coke for preheating	0	1	0
Salt	0	0	6
Labor	0	7	0
	£1	8s	6d

* "A New Electric Hardening Furnace", E. Sabersky and E. Adler, Trans. Faraday Soc., Vol. 5, 1909, p. 15.

	Gas	Electric
Cost per cutter	10d	3.4d
Time	50 hours	10 hours
Cost per hour	1s 8d	2s 10d

Third Method: The third method of applying electricity is accomplished in a modified type of resistance furnace, in which an alternating current is used.

This type of furnace (Fig. 12), developed by the author, is especially applicable to the treatment of steel and iron. It consists of a conductor carrying the current and surrounding the metal, which, in this case, acts as the carrier of the magnetic lines of force and, at the same time, as the secondary of a transformer. The eddy currents and magnetic hysteresis heat the metal.

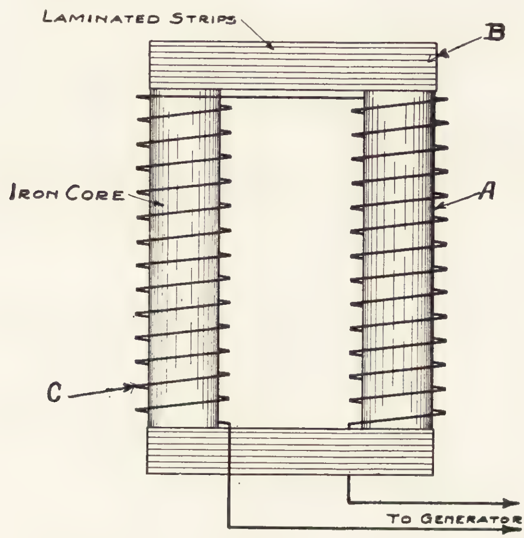


Fig. 12.

A simple form of the apparatus is constructed as follows:

The metal to be heated, A, is contained in the coil, C, which carries an alternating current of about 60 cycles. The metal is joined magnetically by the laminated yokes, B. The whole is surrounded by a heat-insulating material.

The action of the apparatus is as follows: When the alternating current is applied, a magnetic field is produced, which, in turn, induces eddy currents in the metal, thus transforming the energy of the electric current directly into heat energy in the material.

The following advantages are claimed for this method:

1. The metal is heated uniformly, because of the fact that a difference in temperature would immediately cause a corresponding change of the eddy currents in the metal and thus equalize the temperature.
2. The application of a magnetic field to the metal causes it to expand and contract, thus producing a kneading effect especially desirable at the recalescent point.
3. The heating is carried on uniformly until the recalescence point is reached, when there is a marked change in both the current and electromotive force of the alternating circuit. This effect can be used to automatically control the temperature.
4. Heating or cooling the metal through the recalescent point while under the action of a magnetic field greatly improves its quality (See Pender and Jones).
5. The method is efficient, because the heat is applied directly to the metal, and thus it is heated uniformly.

It is particularly applicable to large pieces, and has been used extensively for the treatment of automobile engine pistons to remove the stresses due to casting. This was accomplished without subjecting the metal to high temperatures.

DISCUSSION

Mr. J. B. Fisken,* Fel. A. I. E. E., pointed out that mining companies have use for two types of electric furnaces. The muffle furnace is one type which will have a great application on account of its constancy of temperature. An electric furnace for heating drills would be very superior to the oil furnace, as it avoids transporting oil into the mountains, whereas the electric current is very easily transported. Mr. Fisken.

* Washington Water Power Co., Spokane, Wash.

Paper No. 138

THE MECHANICAL PROBLEM OF THE ELECTRIC LOCOMOTIVE.

By

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INTRODUCTORY.

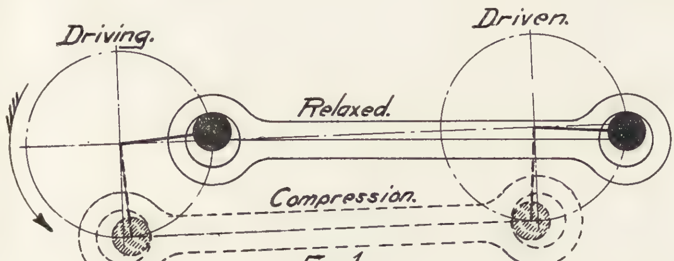
The transmission of tractive effort from the motors to the driving wheels stands pre-eminent among the multitude of mechanical problems presented by the Electric Locomotive.

The stresses due to the static and dynamic interactions of the various elements of the transmission systems of crank-and-rod coupled electric locomotives, have been the subject of an active discussion during recent years in the Continental technical press, and elaborate formulae for the approximation of existing stresses have been developed. A careful review of all the papers that have come to the writer's attention, as listed in the Bibliography, leads him to the conclusion that all the formulae that have been derived are invalidated by the omission from the fundamental hypothesis of certain important existing forces, or deflections. The discussion of the dynamic phenomena seems premature, in view of the wide divergence of opinion concerning the static force distribution.

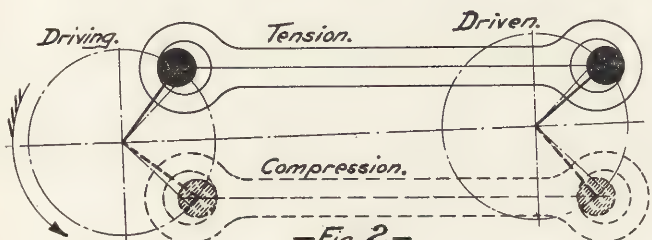
It is the purpose of this paper to approach the static problem from a somewhat different angle than has been previously employed, and to discuss a number of diagrams worked out along the lines of the suggested method of analysis. The fundamentals of this static analysis were worked out several years ago, previous to the building of any electric locomotives equipped with cranks, rods, and jack-shafts. Quite a number of locomotives in which the conclusions drawn from this analysis were embodied have been in service a number of years, and on none of them has

the transmission been subject to either shaking or resonance phenomena, or to breakage.

The discussion in this paper will be strictly limited to "Types", suggesting methods by which specific locomotives may be analyzed by those interested. In no diagrams are concrete values assumed that are directly borrowed from any existing



—Fig. 1.—



—Fig. 2.—

Eaton

locomotive. The "Types" discussed, however, have all been actually constructed.

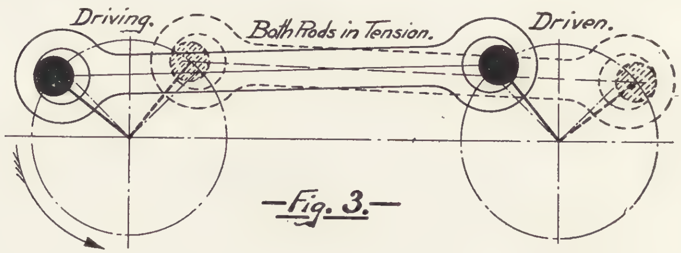
FUNDAMENTAL DIFFERENCE BETWEEN STEAM AND ELECTRIC ROD-DRIVE.

On a steam locomotive the pistons, piston rods, main rods, and main driving axle constitute a statically determinate system, the indicator diagram and the masses of the various elements supplying all the data necessary for a complete analysis of static and dynamic phenomena.

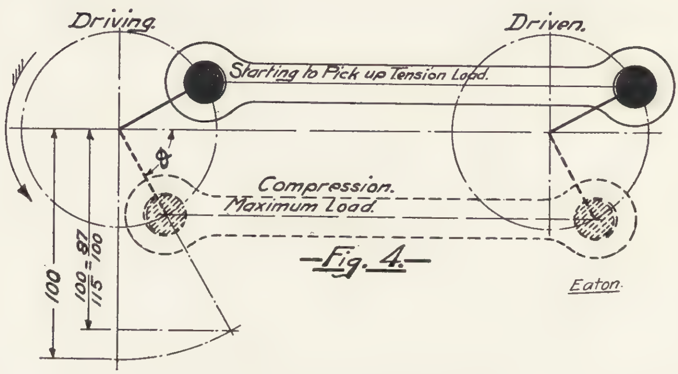
In contrast with this determinate mechanism, practically all electric locomotive crank-and-rod drives are statically indeterminate, to the extent that no accurate general formulae can be derived that will determine the distribution of tractive effort between the near and the far rods at all points of revolution.

SEQUENCE OF EVENTS IN CRANK-AND-ROD TRANSMISSION.

If the material of the shafts, crank pins, bearings, framing, etc., were absolutely rigid, and appreciable play existed in the various pin and journal bearings, a sudden interchange of load between the near and far sides would occur at points approximately 45° from the plane of shaft centers. This is illustrated in



—Fig. 3.—



—Fig. 4.—

Figs. 1, 2, and 3, where the pin clearances are exaggerated for the sake of clearness.

For the sake of uniformity, anti-clockwise rotation, with the near crank 90° ahead of the far crank, will be adopted in all cases.

Centrifugal force has been disregarded in these figures.

The weight of the rods has been considered only in the case of the near rod in Fig. 1.

It is evident that the near rod, when on the dead center, as in Fig. 1, can carry no load, since it hangs loosely on its pins. As rotation occurs, the near rod will continue in its relaxed posi-

tion (if the material is rigid) till the position of Fig. 2 is reached. There will then be, as stated, a sudden transfer of load to the near rod, which will carry the entire load till the position of Fig. 3 is reached. Then the far rod will again assume the entire load. The angle of advance of the driving cranks, and the angle of lag of the driven cranks, is, with rigid material, a function of the pin and journal clearances. Since the error involved by neglecting this angle is, in the static analysis, small compared with other errors that cannot be eliminated, this angle will be disregarded. It will, therefore, be assumed that when the cranks are on the 45° points, the tractive effort is equally divided between the two rods. It is evident that when one rod and its pin are in the plane of the shaft centers, the entire tractive effort is carried by the rod whose cranks are at 90° from the plane of centers. The stress imposed on the rod in this 90° position will be termed a 100% stress. (For example, the far rod in Fig. 1.) Referring further to Fig. 1, as anti-clockwise rotation starts, the far rod will approach the plane of the shaft centers. It is evident, as above stated, that the near rod cannot at once come into action on account of the pin and journal clearances. The stress on the far rod during the period in which that rod transmits the entire tractive effort will, therefore, increase to a greater value than the 100% stress, following the law $P = \frac{100\%}{\text{Sin } \theta}$; where P is the rod stress and θ is the angle between the crank and the line of shaft centers. (See Fig. 4.)

MAXIMUM STRESS CONDITIONS.

Abandoning the inaccurate assumption of rigid material, the point at which the stress on the far rod is a maximum can be approximately determined by a cut and try method that will be described later. It is first necessary to analyze briefly the various conditions under which the maximum stress may occur.

These conditions will fall under the following general heads:

Regular Service	Slipping wheels at maximum adhesion
	Running at maximum speed (rod whipping)
	Running at critical speed (resonance)
	Brake application
Emergencies	Flashing or bucking of motors
	Errors of assembly
	Collision, derailment, etc.

Slipping Wheels at Maximum Adhesion.

Numerous tests with accurate dynamometer cars show that electric locomotives of various types and operating on various electrical systems may have a coefficient of actual adhesion of as much as 40%, with sanded rails. The term "actual adhesion" refers to the adhesion of the light axle from which weight has been transferred by the couple which balances the couple formed by the pull on the draw-bar and the rail reaction. (For a discussion of "Weight Transfer", see Electric Journal, Vol. VIII, p. 257.) This 40% adhesion is greater than can be developed with the average steam locomotive. This is due to the fact that the tractive effort of the electric locomotive can be so controlled that, as the slipping point is approached, the increments of increase in tractive effort are small; and, also, because on any control notch the starting tractive effort is practically the same at all points of rotation. With most steam locomotives, there is a point of rotation where the tractive effort is considerably above the average; and the wheels start to slip on this peak, and continue to slip on the points of lesser tractive effort, due to the drop in the coefficient of adhesion after the slipping starts. The rods, pins, etc., should, therefore, be proportioned for 40% adhesion.

Running at Maximum Speed.

The centrifugal, or whipping strains, on the transmission present the same problem as the parallel rods of a steam locomotive, with one exception, which will be discussed under "Flashing of Motors".

Running at Critical Speed.

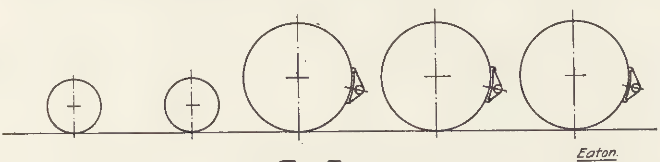
Resonance at critical speeds forms a problem which requires an independent dynamic analysis, and is referred to without detailed discussion at this time. It is entirely possible, and further, highly probable, that in cases where resonance does occur the absolute maximum stresses set up will be those occurring under resonance conditions.

Brake Application.

The effect of brake application under various conditions must be analyzed on each specific locomotive. There is, however, one point peculiar to the electric locomotive which makes a particular type of brake rigging very desirable, in order to reduce the stresses and maintenance of the transmission.

On steam locomotives, it is very general practice to locate the driving wheel brake-shoes as shown in Fig. 5. This arrangement imposes no serious strains on the transmission, since, under brake application, each driving axle advances approximately the same distance, relative to the locomotive framing; and the main rod carries none of the horizontal component of brake-shoe pressure, because the steam load on the piston is practically unchanged by the slight longitudinal displacement that occurs. There are, of course, other advantages, particularly for steam locomotives, in the brake-shoe location illustrated in Fig. 5; but as they do not bear directly on the transmission, they will not be discussed.

In practically every electric locomotive on which crank-and-rod transmission has been applied there is at least one shaft carried in bearings, which, in the longitudinal direction, are rigidly



—Fig. 5.—

seated in the locomotive framing. This shaft is crank-and-rod connected to the driving axles. If the brake-shoes are so located that during brake applications the driving axles are all displaced in the same direction, relative to the fixed shaft, it is evident that with certain combinations of clearances the entire horizontal component of brake-shoe pressure may be imposed on the fixed shaft bearings, through the rods and pins. The strains thus needlessly imposed upon the transmission are in addition to the inherent strains, and will increase the maintenance charges. Where the fixed shaft is located in the middle of the driving wheel base, conditions may be materially improved by locating the brake-shoe symmetrically, relative to the fixed shaft. The horizontal component of brake-shoe pressure of each driving axle may then be imposed on the pins and rods of that axle, but the fixed shaft will carry only any existing differential load. The so-called clasp brake constitutes the most complete solution of the difficulty. In this braking system, the brake-shoe is located on each

side of each driving wheel. Then, when the brakes are applied there is at the worst only a small differential force tending to displace the driving axles longitudinally relative to the locomotive framing, and the transmission is relieved to the greatest possible degree of the horizontal component of brake-shoe pressure. There are many other advantages inherent in the clasp brake. The chief disadvantage lies in the increased number of parts.

Flashing or Bucking of Motors.

Oscillograph measurements show that when a direct-current motor flashes, the surge of current may cause the torque to rise in a very small fraction of a second to as high as twenty times the normal torque. The tendency to flash increases as the speed increases. The damage that may result from a motor flash, with a crank-and-rod connected direct-current locomotive, is a function of the time in which the main circuit breaker will interrupt the current. If the circuit breaker is sufficiently quick-acting to open the circuit before the torque rises to a dangerous value, and if the breaker will, with reasonable inspection, keep in proper calibration, then no further provision is essential. The ultimate degree of safety, however, is insured by providing some form of slip clutch in the armature, or an equivalent mechanical circuit breaker. No crank-and-rod connected main line direct-current electric locomotives have been built, to date, without a device of this class.

The electrical circuit breaker must be set with sufficient margin to remain closed when the locomotive is exerting its maximum starting tractive effort. The mechanical breaker must have a margin above the normal setting of the electrical breaker, and the transmission must be proportioned to withstand the combined longitudinal and whipping stresses involved in slipping the mechanical breaker when a flash occurs with the locomotive running at the absolute maximum speed.

There is a definite reason which renders it advisable to proportion crank-and-rod transmission more conservatively on certain electric locomotives than is essential, at least, on the main rods of the great majority of steam locomotives. The electric locomotives referred to are those operating in tunnels and on viaducts, or wherever a continuous, hard roadbed exists. Under such conditions, the danger of a derailment resulting from a

broken pin or rod is much greater than that involved over the comparatively soft roadbed which is standard for steam operation. There is, of course, a certain chance, in steam operation, that a wild rod end will strike a culvert or bridge. The fact remains, however, that with steam locomotives it is very rarely that a broken rod or pin causes a derailment. Furthermore, most of the electric locomotives with crank-and-rod transmission, now in actual use, are in a class of passenger service where the greatest possible attention to detail is essential to insure safety.

Errors of Assembly.

Serious strains may be imposed upon the transmission by errors of assembly; the most frequent being errors of tram and of quarter. Provision against such errors can be made, partially, by the production of designs which lend themselves readily to correct machining and assembly. The ultimate degree of protection lies in the introduction of flexible elements at critical points in the transmission.

Collision, Derailment, etc.

In the same manner, the only provision that can be made against damage under derailment, collision, or other wreck conditions is the adoption of such precautions in design and operation as will minimize the liability of these emergencies arising.

Each of the possibilities for maximum stresses must be examined in analyzing any specific locomotive. In case an armature clutch is provided, the force required to slip the clutch, properly combined with the whipping strains at absolute maximum speed, has been found to give a conservative basis for designing the transmission.

METHOD FOR DETERMINING MAXIMUM STRESS.

The approximate method, referred to above, for determining the maximum stress after the maximum condition is determined, is as follows:

Assume all dimensions of a specific transmission, including all pin and journal clearances, and including the framing in which the shafts are mounted.

Examine the specific transmission with a view to determining which of the following deflections, etc., are of magnitude worthy of consideration:

1. Torsion of the driving shaft
2. Bending of the driving shaft
3. Elimination of clearance in the driving-shaft bearings

*4. Compression of the driving-shaft bearing brasses
*5. Torsion of the driving crank
*6. Bending of the driving crank

7. Bending of the driving-crank pin
8. Elimination of clearance in the driving-pin bearing

*9. Compression of the driving-pin bushing

10. Compression or elongation of the connecting rod

*11. Compression of the driven-pin bushing

12. Elimination of clearance in the driven-pin bearing
13. Bending of the driven-crank pin

*14. Bending of the driven crank
*15. Torsion of the driven crank
*16. Compression of the driven-shaft bearing brasses

17. Elimination of clearance in the driven-shaft bearing
18. Bending of the driven shaft
19. Torsion of the driven shaft
20. Bending of the locomotive framing
21. Torsion of the locomotive framing

In electric locomotive practice, in the United States, the parts usually approximate rigidity closely enough to make it safe to neglect the starred items, 4, 5, 6, 9, 11, 14, 15 and 16. In studying any new design, however, all twenty-one items should be roughly evaluated in a preliminary survey, before eliminating any from further consideration.

The position where the far rod will be subjected to maximum static stress will, evidently, be between the positions $\theta=90°$ and $\theta=45°$. (See Fig. 4.) Select a point about midway between these two positions, and assume arbitrarily a definite division of effort between the near and far rods. Start with the near driving-crank pin as origin and locate by rectilinear coordinates the following points of the transmission, in the order named, making allowance for clearances and for essential deflections:

1. Near driving-shaft bearing
2. Far driving-shaft bearing
3. Far driving-crank pin
4. Far driven-crank pin
5. Far driven-shaft bearing
6. Near driven-shaft bearing
7. Near driven-crank pin

Calculate the distance between the near driving-crank pin and the near driven-crank pin. If this distance checks with the length of the near rod, under the assumed stress and clearance conditions, then the assumed distribution between the near and far rods is approximately correct. If the rod length fails to check, the distribution assumption must be altered and the calculations repeated.

Having determined the distribution for one point, analyze adjacent points in the same manner. The analysis of three or four points will determine the maximum point with sufficient accuracy for all practical purposes.

The very laborious and approximate method outlined above is offered with a full realization of the errors involved. It is, however, the most accurate method the writer has been able to devise, and has been successful in actual use.

MAXIMUM STRESS IN U. S. PRACTICE.

With the materials, proportions, and clearances customary in electric locomotive practice in the United States, and at 40% rail adhesion, the above method shows a maximum static stress on the rods of about 15% in excess of that imposed at the 90° position. This stress will be referred to as the 115% stress. This value is approximately correct under the assumed conditions, both for the transmission from the motor shaft to the jack-shaft, and from the jack-shaft to the axle. This stress occurs practically at the point where the other rod comes into action. It will, therefore, be assumed that, in the position shown in Fig. 4, the far rod carries a 115% stress and the near rod carries a 0% stress. As rotation advances beyond the position shown in Fig. 4, the near rod picks up its load with sufficient rapidity to make this assumption correct within the limits of accuracy inherent in the method.

It is evident that the maximum stress will vary in the following manner:

First, The maximum stress will vary as an inverse function of flexibility. This constitutes an argument in favor of heat-treated and alloy steels, since high unit stresses, and therefore greater deflections, are permissible.

Second, The maximum stress will vary as an inverse function of the load.

Third, The maximum stress will vary as a direct function of the speed (with motors of series characteristics).

Fourth, The maximum stress will vary as a direct function of pin and journal clearances.

This constitutes an argument for close inspection and maintenance of pins, bushings, journals, and brasses; and also for the adoption of designs lending themselves to small clearances and cheap, quick replacements. In none of the above features are the arguments necessarily conclusive. They must be balanced against the other existing arguments for the purpose of selecting that compromise offering the greatest over-all advantage. Having once arrived at the figure, 115% for maximum static stress, under a definite set of conditions, it is sufficiently accurate to use this figure for all designs consistently worked out in accordance with the same general practice. For any radical departure of practice, a specific maximum stress should be derived.

POLAR DIAGRAMS.

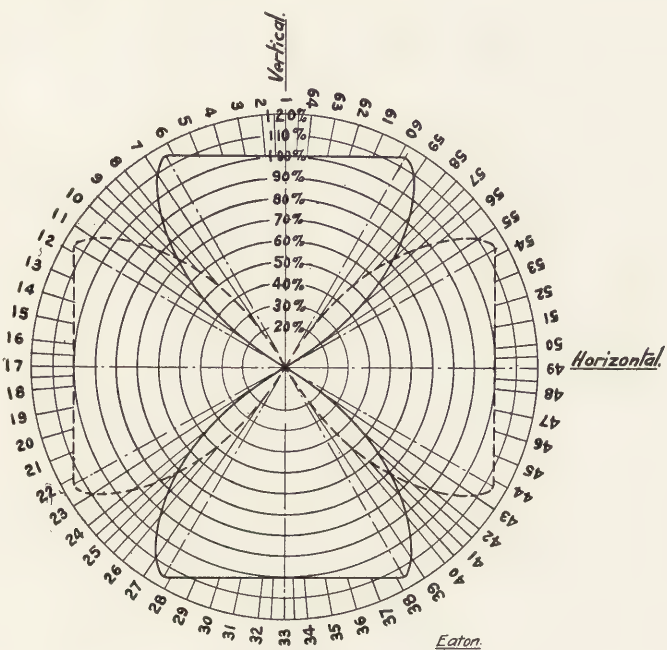
It now becomes possible to construct an approximate polar diagram, Fig. 6, which will be characteristic for all cases of driving and driven shafts, crank-and-rod connected, whose maximum stress is 115%.

There are, evidently, eight positions of rotation at which the pin pressure can be quite accurately determined, viz., $\theta=0$, $\theta=45$ and $\theta=90°$, etc. Since these eight points are equally distributed around the crank circle, it becomes natural to divide the crank circle into multiples of eight. Sixty-four main points are, therefore, adopted; and where the violence of force fluctuations renders it necessary, fractional intervening points are interpolated.

Referring to Fig. 6, points 1 to 6 inclusive are correct; point 9 is very nearly correct; and points 7, 8, 10 and 11 are approximations, the curve being so constructed that it is a fair curve; and, at the same time, the sum of the turning moments on the near and far cranks is always equal to the constant turning moment of the motor.

In this diagram, the intensity of pin pressure corresponding

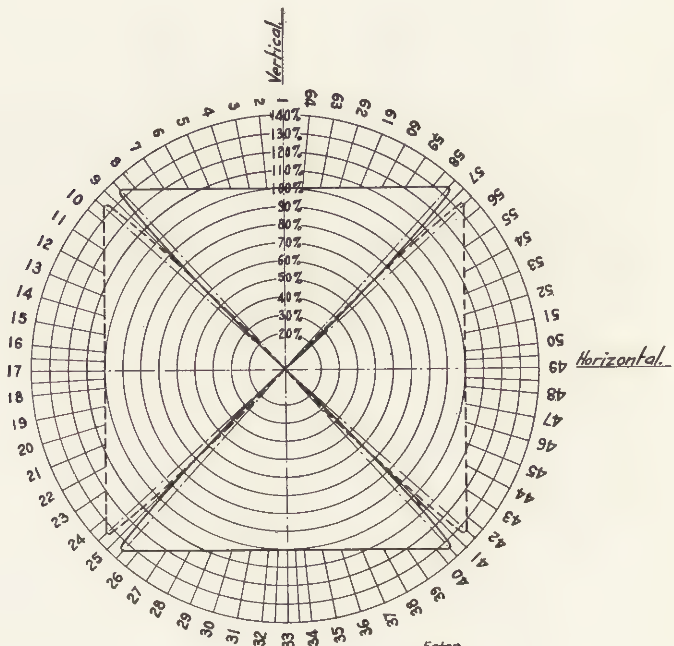
to any crank position is measured by the length intercepted between the center and the curve, on a radius passing through the given crank position. For example, at point 7 the pressure on the near pin is 110%, and on the far pin is between 20% and 30%. This diagram, in common with all polar diagrams in this paper, covers the intensity of the force, but gives no data regarding the direction or the point of application of the force.



—Fig. 6.—
FORCE DISTRIBUTION
between
NEAR AND FAR CRANK PINS
at
MAXIMUM TRACTIVE EFFORT.
BASED ON A MAXIMUM STRESS RATIO OF 115 %.

With motors of series characteristics, as the speed increases, the tractive effort decreases. The deflections, therefore, decrease and the clearances assume a greater importance as the speed increases. There will be some deflections; and the maximum rod stress will probably never reach the limiting value of $\frac{100\%}{\text{Sin } 45}=141\%$. This 141% stress might be reached, or even

exceeded, if the interchange of effort between the near and the far rods were accompanied by a shock, as is claimed in Elektrotechnische Zeitschrift, May 28 and June 4, 1914. (See Bibliography.)* As will be shown later, however, the rod is, at high speed, always held in intimate contact with its pin by centrifugal force (a fact apparently overlooked in the paper referred to above).



—Fig. 7.—
FORCE DISTRIBUTION between NEAR AND FAR CRANK PINS at MAXIMUM SPEED.
BASED ON A MAXIMUM STRESS RATIO OF 135%.

Without going through the elaborate deflection calculation, the maximum condition that may be expected is closely approximated by Fig. 7, where the law $P = \frac{100\%}{\text{Sin } \theta}$ is assumed to apply, except over a very acute angle of interchange of effort between the near and the far rods. In case of a motor flash, and attendant high

* J. Buchli.

pressure at high speed, considerable deflection will occur because of continual intimate contact of the rods and pins. The action of the pin will be a rolling from a driving to a retarding position in the rod bushing, rather than a jumping across the bearing clearance.

It should be noted here that in recent discussions the statement is freely offered that the distribution of forces between the near and far rods follows the ''sine law''. Elektrische Kraftbetrieber und Bahnen for Sept., 1910,* shows the assumptions which must be made in order to validate the sine law. The following points may be listed in this connection:

1. With rigid material and no clearances, the system is indeterminate. This being an imaginary case, no further time need be spent in discussing it.

2. With clearances and flexible material, the sine law applies while one rod alone is in action. $P=\frac{100\%}{\text{Sin }\theta}$ (See Fig. 4).

3. During the four angles of interchange of load between the near and the far rods, the distribution of forces is a function of clearances and deflections; and no general law can be derived. Each specific case must be analyzed independently.

Figures 6 and 7 then form the basis from which pressure diagrams may be plotted for the various shafts, bearings, etc., in the transmission of various types of crank-and-rod coupled electric locomotives at maximum tractive effort, and also at maximum speed where the design is such that the maximum stresses are 115% and 135% respectively.

DISCUSSION OF DIAGRAMS.

Before discussing the various diagrams in detail, attention is again specifically invited to the fact that they are offered as illustrating general characteristics, and that no claim is made for complete detail accuracy.

Correct tram and quarter are assumed in all diagrams. In all the pressure diagrams, in position No. 1 the near crank pin is vertically above the shaft center and the far crank pin is lagging 90°, on the basis of anti-clockwise rotation. (See Fig. 8.)

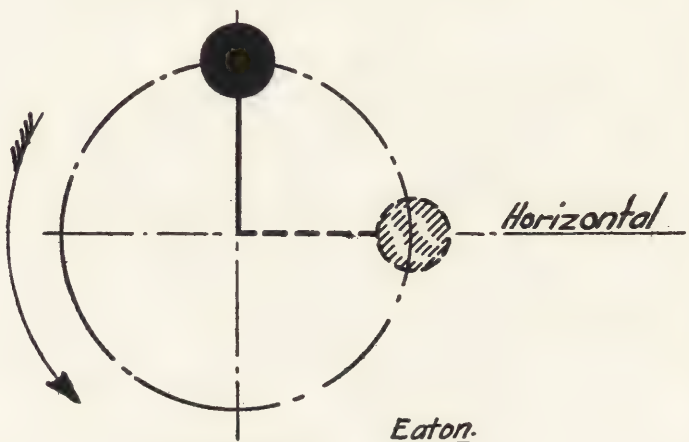
* Kleinow.

The locomotive types outlined in Figs. 9, 10 and 11 will be analyzed. (It is assumed that the total power transmitted is the same in all types.)

Type "A" Locomotive—Maximum Speed.

Fig. 12 shows the relative intensity, the direction, point of application, and sequence of forces acting on the outer crank pin of the jack-shaft. The forces plotted are the resultants of

1. Rod pressure due to transmission of tractive effort.
2. Centrifugal force, due to rod weight.



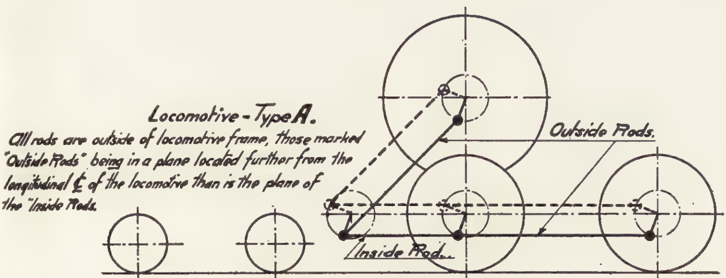
—Fig. 8.—
Position No 1.

The rod weight itself is disregarded, being very small, compared with the forces above noted.

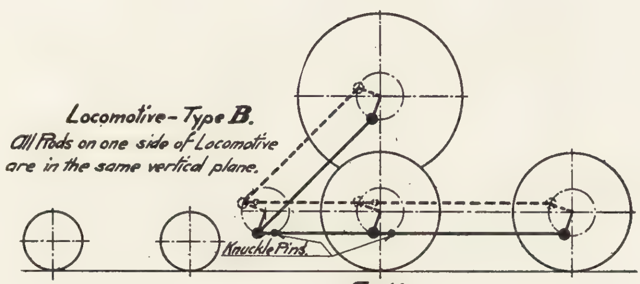
The ratio of minimum to maximum pin pressure will vary as a direct function of the ratio of rod weight to tractive effort. In the particular case shown, the minimum pin pressure is 41% of the maximum. This is based on rods with non-adjustable heads, laid out in general accord with American steam locomotive practice.

The rod bushing is at all times held firmly in contact with its pin. This is in marked contrast with the theory advanced in Elektrotechnische Zeitschrift, as referred to above, where a minimum pin pressure of zero at maximum speed is assumed.

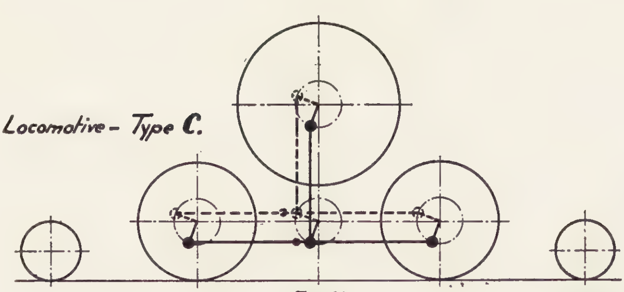
During a single revolution of the crank, the point of contact



—Fig. 9.—



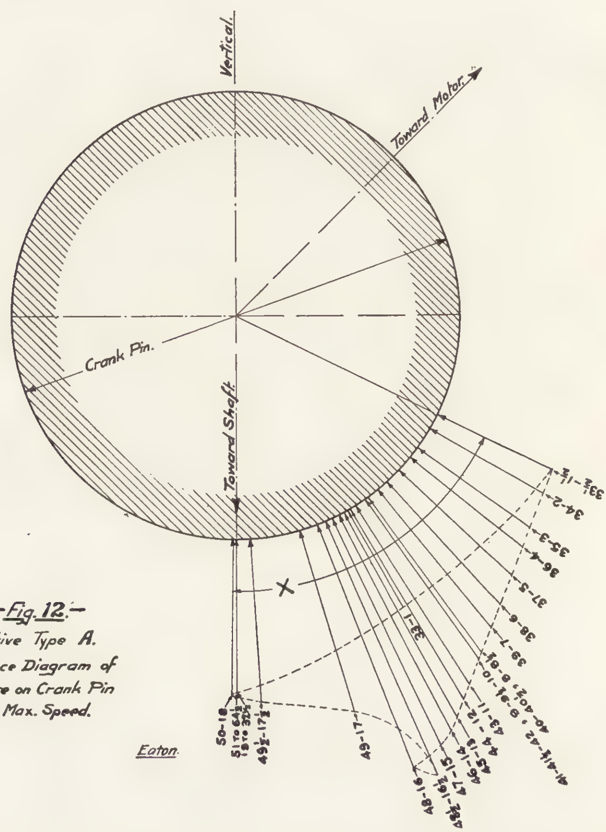
—Fig. 10.—



—Fig. 11.— Eaton.

between the pin and the rod bushing makes two complete oscillations forward and back over the angle "X" (see Fig. 12), following in each complete oscillation exactly the same cycle.

There is a pronounced tendency for the pin to wear eccentric. There is only a small angular displacement of the range of contact when the direction of revolution is reversed. Therefore,

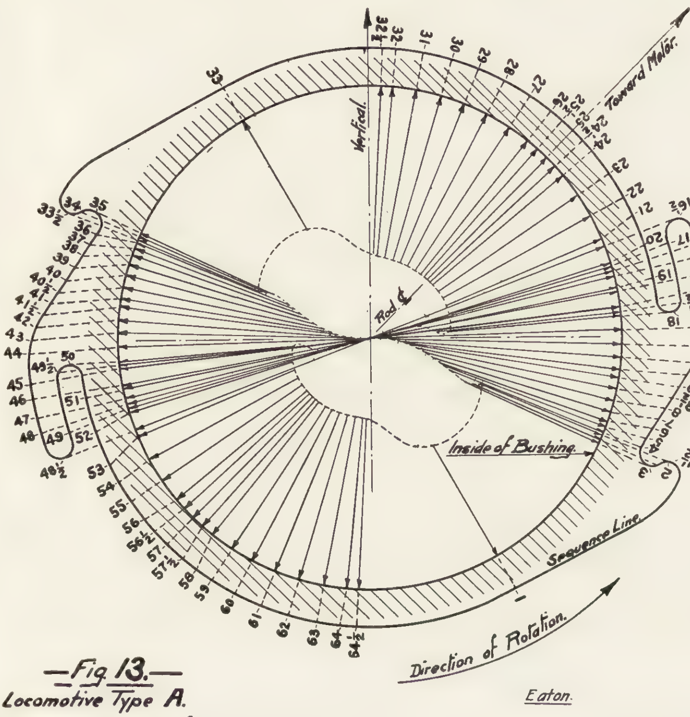


—Fig. 12.—
Locomotive Type A.
Sequence Diagram of
Pressure on Crank Pin
at Max. Speed.

the eccentric wearing tendency is not materially different under one direction or two direction operation of the locomotive.

The lubrication of the pin and bushing can be more easily analyzed in connection with the diagram of forces acting on the rod bushing, and will, therefore, be included in the discussion of Fig. 13.

Fig. 13 shows the diagram for the motor rod bushing corresponding with Fig. 12. In this, and in all other diagrams which deal with pressures acting on the inside of a cylindrical shell or bushing, there is insufficient space inside the base circle to accommodate the identifying point numbers. A sequence line is therefore drawn outside the base circle, the shape of this line being arranged so that the point numbers occur on the sequence line in consecutive order from 1 to 64½. The shape of the sequence



—Fig. 13.—
Locomotive Type A.
Sequence Diagram of
Pressure on Rod Bushing
at Maximum Speed.

line also guides the eye in following the travel of the point of contact between the shaft or pin and the shell or bushing. Several of the pressure lines exceed the radius of the base circle. It is, therefore, not possible to appreciate the values of these forces on this diagram. They may be read by reference to Fig. 12.

In general, the point of contact between the pin and the rod

bushing travels in the same direction as the shaft rotation. There are, however, four regions where the direction of travel of this contact point is reversed.

The point of maximum resultant pin pressure is not on the longitudinal center line of the rod, and the bushing tends to elongate on a line about 45° off of the rod center line.

The most advantageous location for the introduction of lubricant is near the vertical center line, between the points marked 33½ and 33, since this point is furthest removed from the region of maximum pressure. When the clearance between the pin and the bushing is in line with the lubrication opening, thus offering the maximum space for the introduction of lubricant, centrifugal force is tending to force the lubricant to the top of the cup. A compression cup with sufficient force to overcome this tendency is essential for the best results. After the lubricant is once introduced there is a good pumping action to distribute the lubricant over most of the surface. Between the points 48½ and 50, and also between the points 16½ and 18, there is an undesirable reverse wiping action.

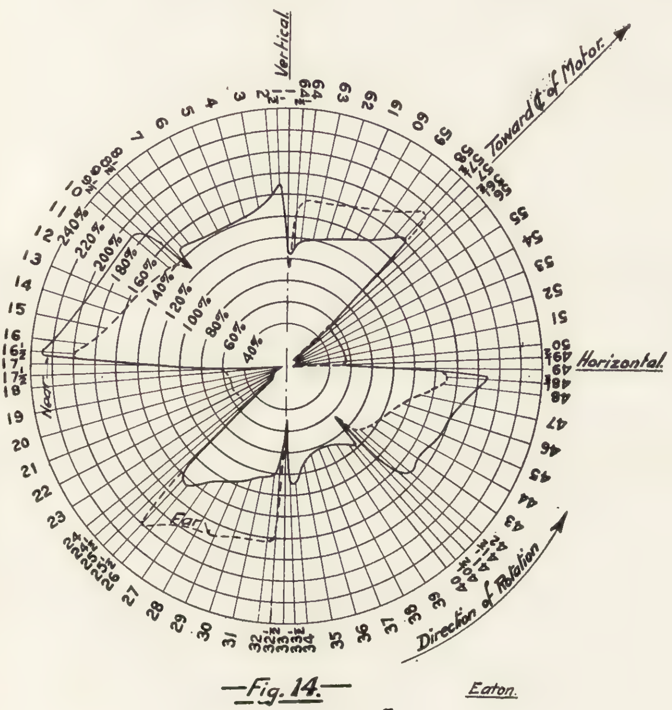
Fig. 14 shows, under maximum speed conditions, the relative intensity of jack-shaft bearing pressure corresponding to the positions of the near crank pin. The diagram does not show the direction or the point of application of the forces. The pressures plotted are the resultant of the pressure due to tractive effort on all four rods connected to the jack-shaft crank pins, together with the weight of the jack-shaft, counterbalances, and that part of the rods carried by the pins. Centrifugal force, due to the rod weights, is not effective on the jack-shaft bearings, being neutralized by the counterbalances.

The near bearing pressures are indicated by full lines, and the far bearing pressures by dotted lines. Between points 1 and 9, and between points 33 and 41, etc., where only a full line is shown, the diagram for the near and the far bearings is identical.

The maximum forces, and the crank positions at which they occur, are different for the near and the far bearings. In the reverse direction of rotation, the maximum pressures on the near and the far bearings are exchanged, so that the total work of friction is the same on the two bearings when the locomotive runs an equal distance, and in similar service, in both directions.

This polar diagram is presented to emphasize the extreme violence of the fluctuation of the forces; between the points 16½ and 18, for example, the pressure dropping from maximum to practically zero.

Fig. 15 offers a replotting of the forces of Fig. 14 arranged to show the relative intensity, and the direction, point of appli-



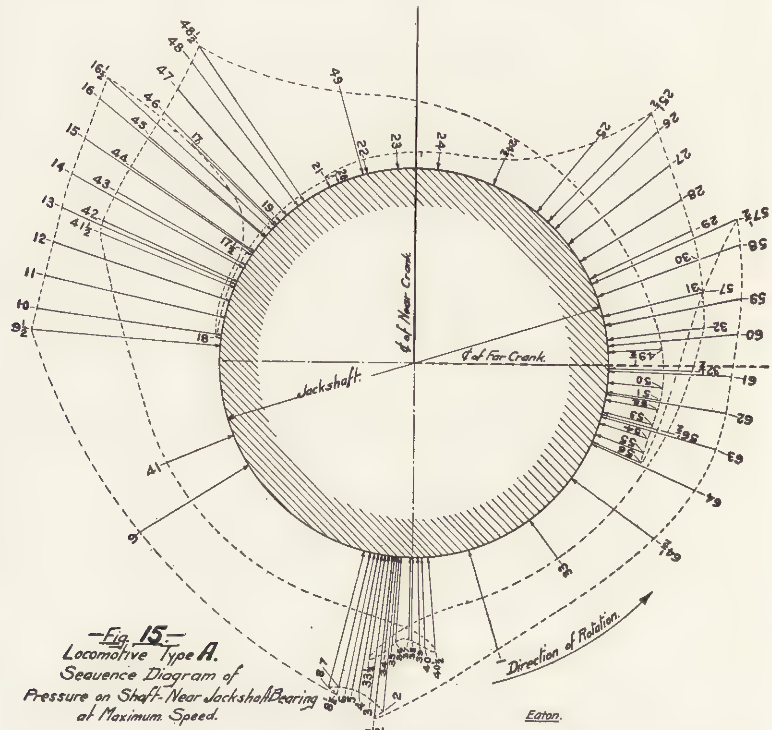
—Fig. 14.—
Locomotive Type A.
Polar Diagram
of
Jack Shaft Bearing Pressure
at
Maximum Speed.

cation and sequence of the forces acting on the near jack-shaft journal.

The contact point travels around the shaft in a direction in general opposite to the direction of shaft rotation. The contact point travels around the shaft twice for every shaft revolution, following a different cycle for each 180° of shaft revolution. There is no marked tendency for the shaft to wear out of round,

either under single or double ended operation. Between the points 49 and 49½, the contact point swings over 90° in 1/128 of a shaft revolution. The pressure concentrates in three separate regions removed from each other, roughly, 120°. In the reverse direction of rotation, the diagram is displaced 180°; the shaft will, therefore, remain practically round.

The corresponding diagram for the jack-shaft at its far bear-

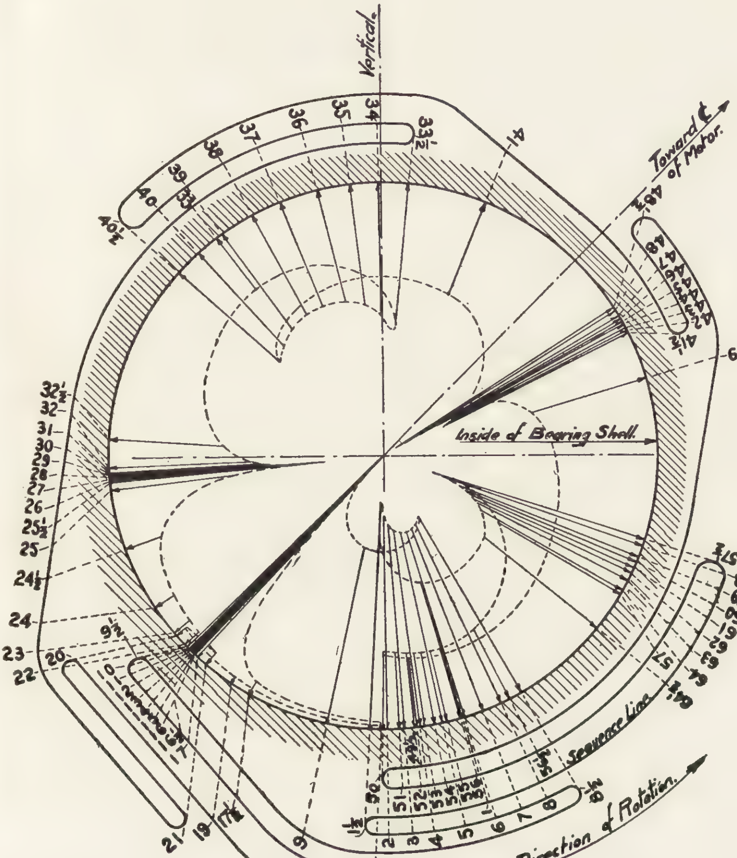


—Fig. 15.— Locomotive Type A. Sequence Diagram of Pressure on Shaft-Near Jackshaft Bearing at Maximum Speed.

ing is very similar in its characteristics, and will, therefore, be omitted.

Fig. 16 shows the intensity, direction, point of application, and sequence of forces acting on the inside of the shell of the near jack-shaft bearing, being a replotting of the forces in Figs. 14 and 15.

While the prevailing tendency of the point of contact is to swing in a direction opposed to the shaft revolution, its detail path is most erratic.



—Fig. 16.—
Locomotive Type A.
Sequence Diagram of
Pressure on Shell - Near Jackshaft Bearing
at Maximum Speed.

The following four facts indicate a tendency for the wear of the bearing brasses to be downward:

(a) Out of a total of 80 points plotted, there are 58 points, or $72\frac{1}{2}\%$, which act on the lower half of the bearing brass.

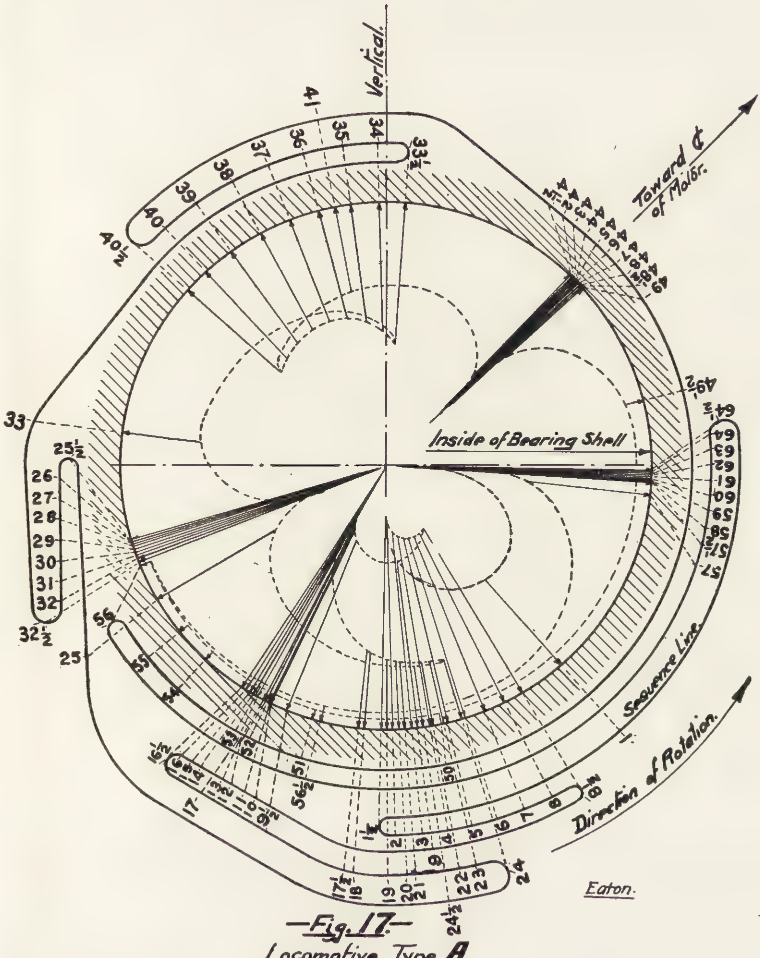
(b) The maximum force is applied on the lower half of the brass.

(c) The only heavy forces acting on the upper half are applied at an angle of only 30° above the horizontal, while heavy forces are applied over the entire lower 90° of the bottom half. It is evident, therefore, that the horizontal plane offers the best location for the split of the brass, if a two-part bearing is used, as a certain amount of wear can be taken up with this design.

(d) There is a possibility of pounding occurring between the points $17\frac{1}{2}$ and 19. At $17\frac{1}{2}$ the pressure has dropped from a maximum to almost a minimum in 1/64 of a revolution. Assuming that the locomotive has 72-in. wheels, and is running at 75 miles per hr., the revolutions per minute of the driver will be $\frac{336 \times 75}{72}=350$. The time involved in passing from $16\frac{1}{2}$ to $17\frac{1}{2}$ will then be $\frac{60}{350 \times 64}=0.0027$ sec. The elastic recoil of the parts may be sufficient to cause the shaft to jump and pound in the bearing. This belongs properly to the dynamic analysis, but is germane to the discussion of wearing tendency. There is no similar phenomenon occurring in the upper half of the brass. Of course, if a jump does occur near $17\frac{1}{2}$, there might be a blow delivered in the upper half, but the return blow on the lower half would be greater, as gravity would subtract from the upward and add to the downward force.

The erratic travel of the point of contact militates against good lubrication, as there is no steady, smooth pumping of the oil film through a clearance that tapers gradually to the working contact.

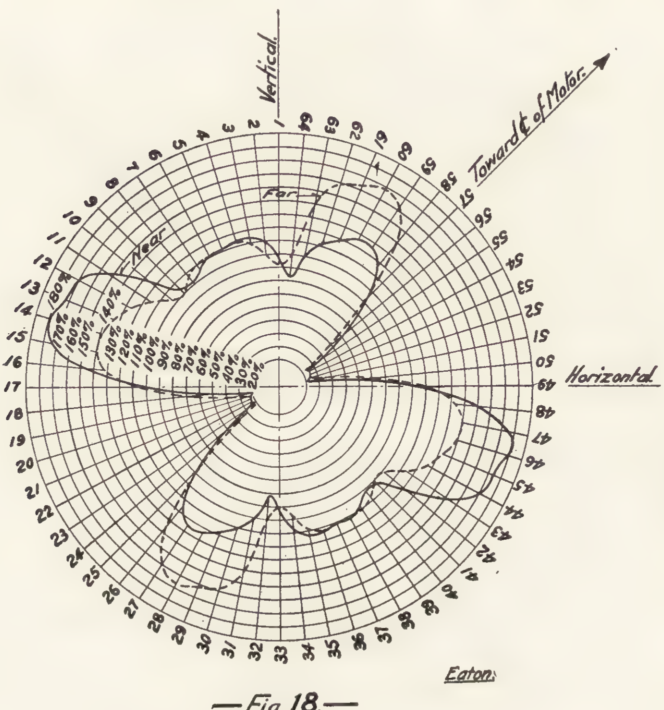
It will be shown later that during a hard start the wearing tendency is practically the same in the upper and lower halves of the bearing brass. The nature of the actual wear then becomes a function of the service. If the locomotive works on a grade, and is doing a lot of heavy pulling, the bearing brass may be expected to wear in all directions, i.e., to increase in diameter, remaining



—Fig. 17—
Locomotive Type A.
Sequence Diagram of
Pressure on Shell – Far Jackshaft Bearing.
at Maximum Speed.

roughly circular. If, on the other hand, the service is starting a train on the level, and running at high speed for long distances, the bearing brass may be expected to wear downwards.

Fig. 17 shows, for the far jack-shaft bearing, data corresponding to that plotted in Fig. 16 for the near jack-shaft bear-

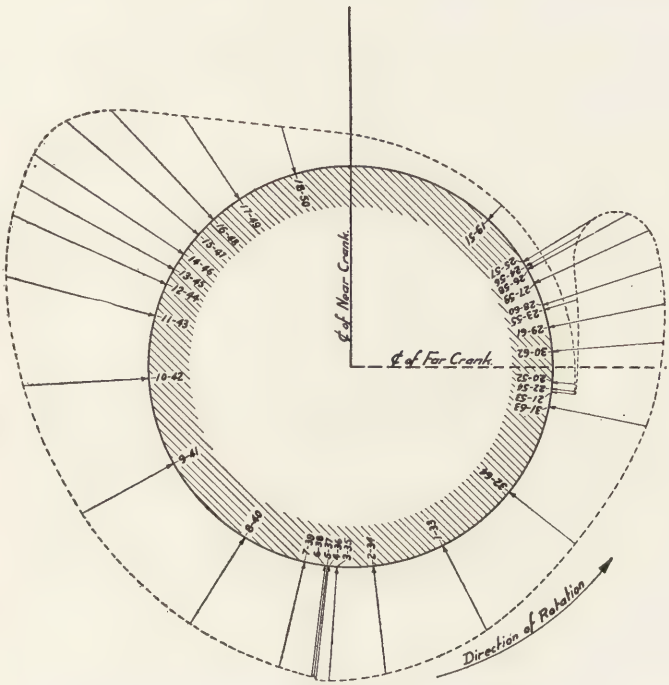


—Fig. 18.—
Locomotive Type A.
Polar Diagram of
Jack Shaft Bearing Pressure
at Maximum Adhesion.

ing. The general characteristics of the two diagrams are very similar. The regions of maximum pressure concentration, however, are differently located. There is, also, a wider angularity in the low pressure region from point 49½ to point 56, and back to point 57. The tendency of the shaft to hammer in its bearing is obvious.

Type "A" Locomotive—Maximum Adhesion.

Fig. 18 shows, under maximum adhesion conditions, data corresponding to that plotted in Fig. 14 for maximum speed conditions. On a percentage basis, the scales in Figs. 14 and 18 are not greatly different, in order to permit of a rough comparison of the relative characteristics of the two diagrams. The concrete value of the forces is, of course, radically different, being depend-



—Fig. 19.— Eaton.
Locomotive Type A.
Sequence Diagram of
Pressure on Shaft—Near Jackshaft Bearing.
at Maximum Adhesion.

ent upon the motor characteristics. If Fig. 14 were plotted, on a force basis, to the same scale as Fig. 18, it would be too small for practical use. A comparison of Figs. 14 and 18 shows clearly the part played by the flexure of material in smoothing out the sharp corners.

Fig. 19 requires no detailed comment, except in regard to wearing tendency. If the locomotive operated at all times in one

direction only, the shaft might tend to wear a slight flat spot centering near point 14. When the direction of rotation is reversed, however, the diagram is displaced 180° relative to the near crank, and another flat, 180° removed, might be produced. Since, however, the forces acting at approximately 90° to the maximum pressure range are very considerable, it seems justifiable to expect very little eccentric shaft wearing to occur.

Fig. 20 exhibits characteristics roughly akin to those of Figs. 16 and 17. As would be expected from the corresponding polar diagrams (Figs. 14 and 18), the force fluctuations are less violent in Fig. 20. The shaft is at all times held firmly in contact with the bearing shell. There is, therefore, little or no tendency for the shaft to jump and pound in the bearing. The lubrication still presents a difficult problem.

The weight of the rotating parts carried in the bearing is so small compared with the other forces that the pressure diagram is practically symmetrical, and, as previously noted, the tendency of wear is to increase the diameter of the bearing.

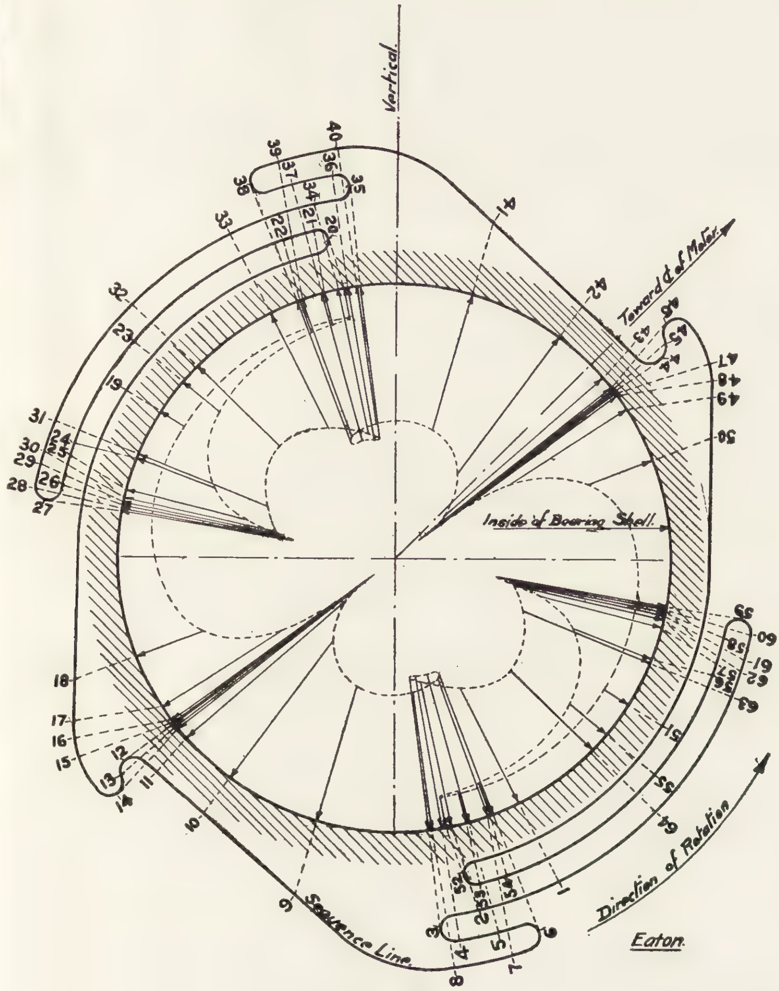
Type "A" Locomotive versus Type "B" Locomotive.

The connecting-rod system of locomotive Type "B" has a higher mechanical efficiency than that of locomotive "A", for two main reasons:

First, There are less crank pins through which the entire tractive effort is transmitted, and

Second, The pressure on the jack-shaft bearings is materially less.

The penalty paid for this gain in efficiency lies in the introduction of knuckle pins into the connecting rod system. Knuckle pins on steam locomotives have been considered objectionable by some operating men, on account of the tendency of the side of the jaw to crack. This tendency has led to the introduction of spherical pins in locomotives for European service. Spherical pins have not been favorably considered in American practice, because of the nicety of machine work required and the difficulty and expense attendant upon proper maintenance. With proper inspection, very few train delays are chargeable to knuckle pin construction on steam locomotives. As far as the writer has been able to learn, there has never been a knuckle pin failure on an electric locomotive in the United States. Knuckle pins, whether



—Fig. 20.—
Locomotive Type A.
Sequence Diagram of
Pressure on Shell – Near Jackshaft Bearing.
at Maximum Adhesion.

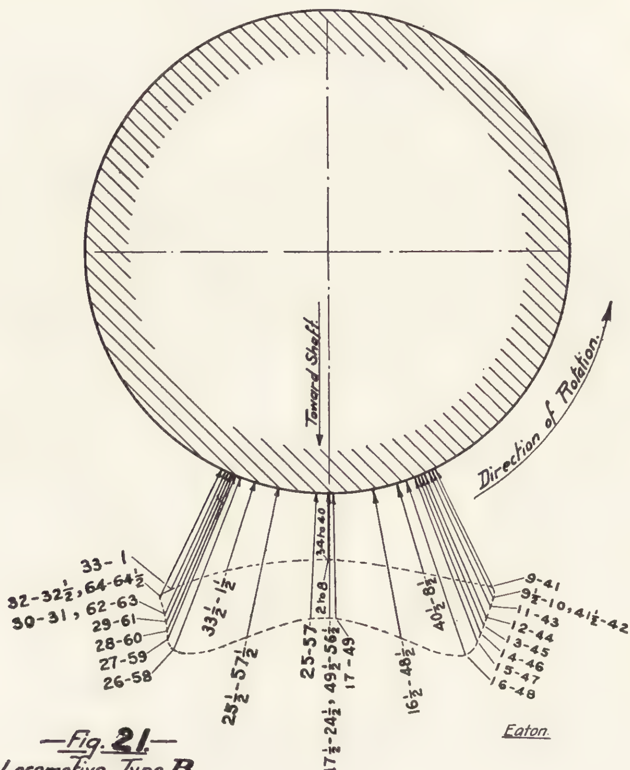
cylindrical or spherical, are objectionable in electric locomotives, because they add slightly to the total clearance that must be taken up in the transfer of tractive effort between the near and the far rods, thus increasing, slightly, the maximum stress.

The advantages and draw-backs of individual crank pins

versus knuckle pin construction demand very thorough analysis before a choice is made, in any specific locomotive design.

Type "B" Locomotive—Maximum Speed.

In Fig. 21, which deals with the jack-shaft crank pin, the scale has, again, been altered slightly in order to retain the diameter of base circle employed in the other diagrams. This was done



—Fig. 21.—
Locomotive Type B.
Sequence Diagram of
Pressure on Crank Pin
at Maximum Speed.

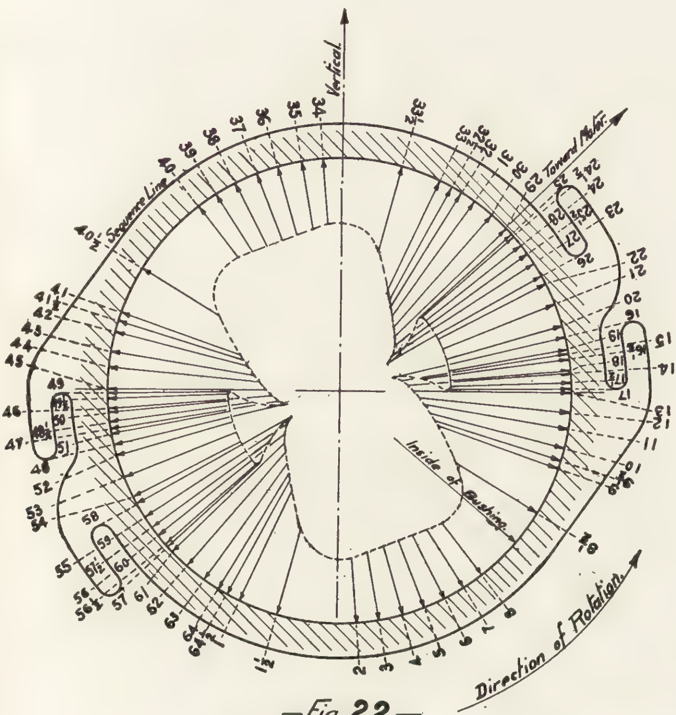
in order to avoid in Fig. 22 the slight confusion existing in Fig. 13.

In Fig. 21 the pressure range is disposed symmetrically relative to a line connecting the center of the crank pin and the center of the jack-shaft. This is in marked contrast to Fig. 12. Here again the rod and pin are at all times held in intimate contact.

Fig. 22 shows an eccentric wearing tendency in the rod bushing. The line of maximum wear is midway between the motor rod and the wheel rod.

Type "B" Locomotive—Maximum Adhesion.

Fig. 23 shows that from points $19\frac{1}{2}$ to $22\frac{1}{2}$ and from points



—*Fig.* **22.**—
Locomotive Type **B.**
Sequence Diagram of
Pressure on Rod Bushing
at Maximum Speed.

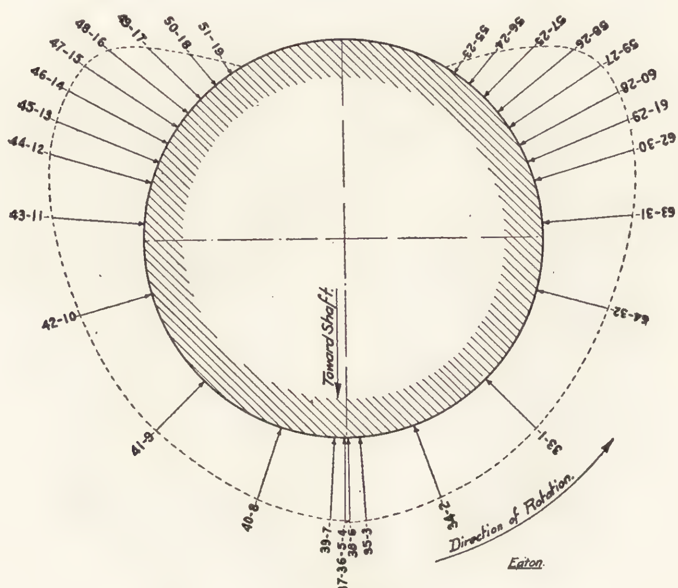
$51\frac{1}{2}$ to $54\frac{1}{2}$ there is no tractive force holding the rod and pin in contact. At point $19\frac{1}{2}$ the rod will drop down on the pin with a slight clank. There will, however, be less clanking on the jackshaft pin than in case of locomotive Type "A", as can be readily seen by an inspection of Fig. 6.

The existence of regions of zero tractive force between the

rod and pin will not give rise to resonance phenomena, because of the slow speed at which these regions occur. As soon as centrifugal force exceeds the rod weight these regions disappear.

At maximum adhesion, the rod bushing acting on the jack-shaft pin of Type "B" locomotive tends to wear practically round, as indicated in Fig. 24.

Fig. 25 shows the same general characteristics for Type "B" locomotive as are illustrated in Fig. 18 for Type "A" locomotive.



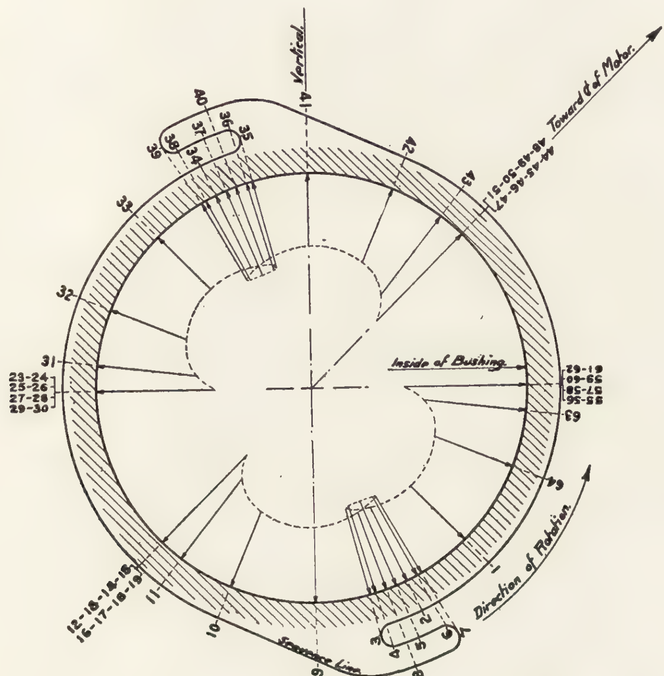
—Fig. 23.—
Locomotive Type B.
Sequence Diagram of
Pressure on Crank Pin.
at Maximum Adhesion.

The maximum pressure, however, is 165% for Type "B", as compared with 180% for Type "A". Thus, with the particular dimensions assumed in the two locomotives considered, the pressure on the Type "A" locomotive is 9% higher than in case of the Type "B" locomotive.

It should be stated that in all the polar diagrams the 100% pressure on the jack-shaft bearing is the same number of pounds

as the 100% pressure on the crank pin, under identical tractive effort conditions.

Another point of difference between Figs. 25 and 18 is that in Fig. 25 the maximum force on the near bearing is the same as the maximum force on the far bearing. In fact, in Fig. 25, the



—Fig. 24.—
Locomotive Type B.
Sequence Diagram of
Pressure on Rod Bushing
at Maximum Adhesion.

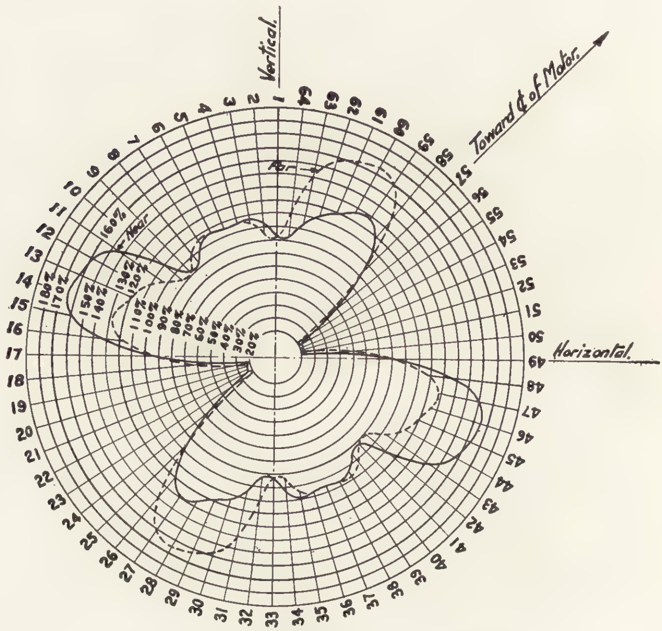
diagram for the far bearing is to the other hand from that for the near bearing.

Type "C" Locomotive—Maximum Speed.

Fig. 26 presents no radical difference from Fig. 21. In plotting this diagram, as in all others dealing with centrifugal force, it is assumed that centrifugal force is equally distributed between

the two pins on which the rod acts. The slightest error in tram would obviously vitiate this assumption.

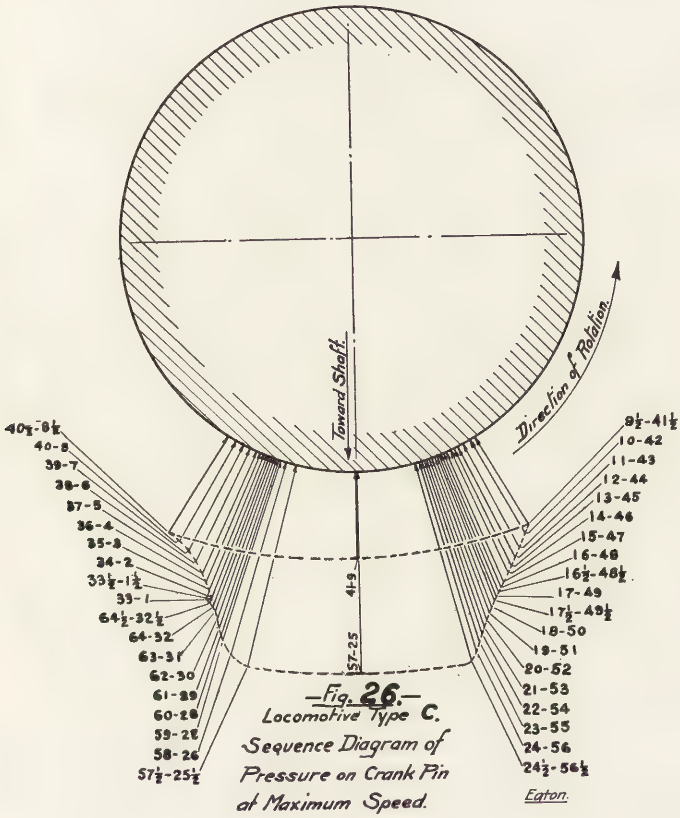
Fig. 27, also, shows the maximum wearing tendency occurring midway between the center line of the motor rod and the wheel rod. When the direction of rotation is reversed the line of wear shifts 90°.



—Fig. 25.—
Locomotive Type B.
Polar Diagram of
Jackshaft Bearing Pressure
at Maximum Adhesion.

Fig. 28 shows at first glance an absence of tendency to eccentric wear. While there is no location subject to marked intensity of pressure, there is, however, marked congestion of pressure on the sides at 90° from the near crank. During reverse rotation, the same shaft areas are subject to pressure congestion. As will be seen later, the same condition exists at maximum speed. There is, therefore, a tendency for the shaft to wear elliptical.

Fig. 29 presents a marked contrast with Figs. 16 and 17. There is no reversal in the direction of travel of the point of contact. There are four locations where the point of contact remains practically stationary for about 55° of revolution. This pause, will, however, interfere less with the maintaining of the oil film

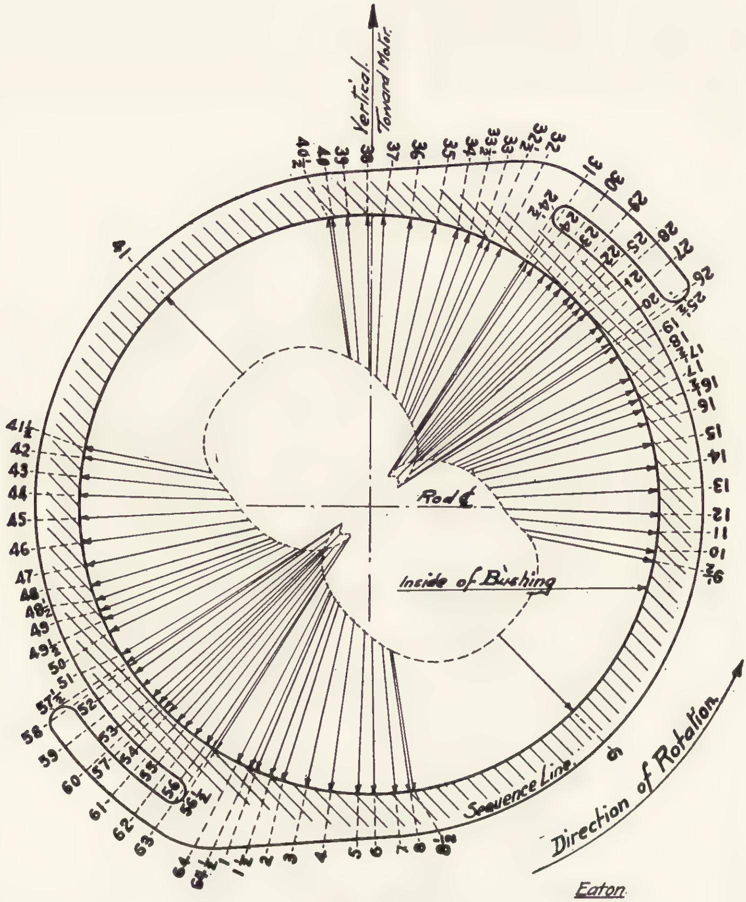


—Fig. 26.— Locomotive Type C. Sequence Diagram of Pressure on Crank Pin at Maximum Speed.

than will the reversals of contact travel existing in Figs. 16 and 17.

The shaft is held at all times in intimate contact with the bearing shell, eliminating pounding tendencies.

The wearing tendency is toward an increased shell diameter, the center of the worn shell tending to be below the center of the new shell.



—Fig. 27.—
Locomotive Type C.
Sequence Diagram of
Pressure on Connecting Rod Bushing
at Maximum Speed.

Locomotive Type "C"—Maximum Adhesion.

Fig. 30 demonstrates that at maximum adhesion the jack-shaft crank pin has the same wearing tendency as is shown for the jack-shaft itself in Figs. 28 and 32. The ultimate wearing tendency of the crank pin will, therefore, depend upon the service

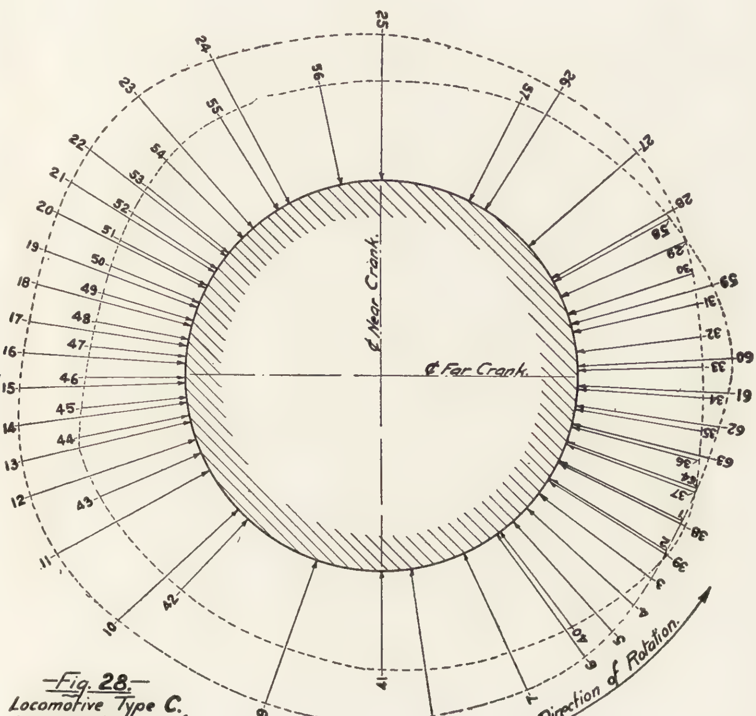
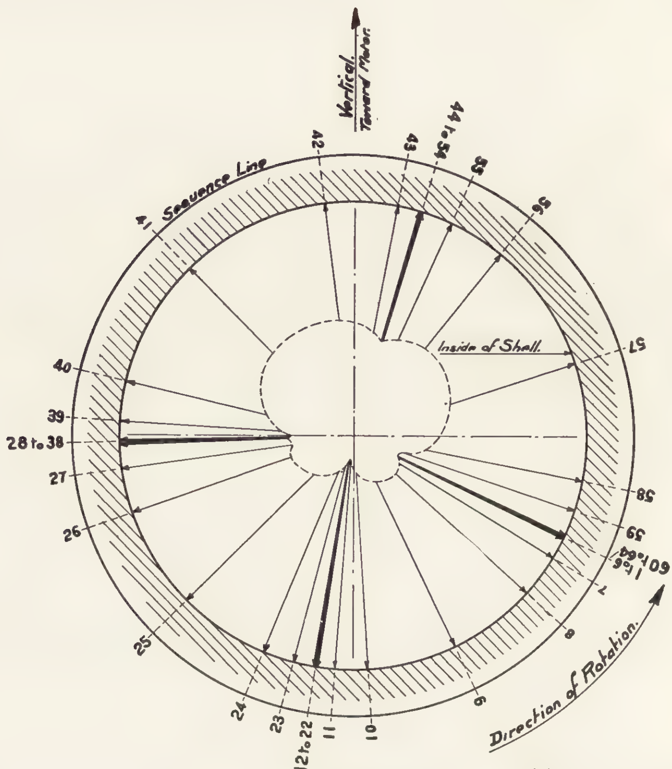


Fig. 28.
Locomotive Type C.
Sequence Diagram of Pressure on Shaft-Near Jackshaft Bearing at Maximum Speed.

performed by the locomotive; the wear being different in heavy slow speed service from that in high speed running.

The rod bushing tends to wear out to a larger concentric diameter at maximum adhesion, as indicated in Fig. 31.

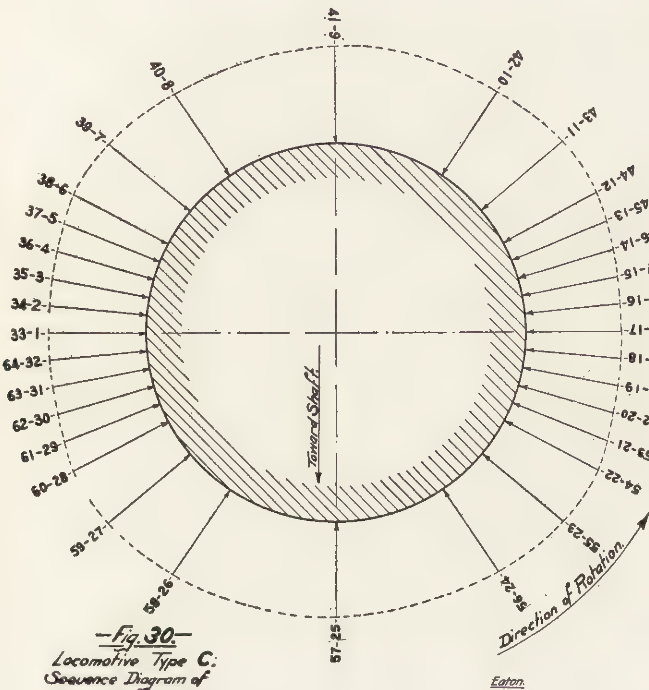
Figs. 32, 33 and 34 require little comment, the characteristics they exhibit being obvious in light of the previous discussions.



— Fig. 29. —
Locomotive Type C.
Sequence Diagram of
Pressure on Shell - Near Jackshaft Bearing
at Maximum Speed.

CONCLUSIONS.

A specific distribution of force between the near and the far crank pins must be worked out to correspond with the standard practice in line with which any given locomotive is designed, since the large number and the involved nature of the existing variables prohibit the development of reliable and universally applicable laws.

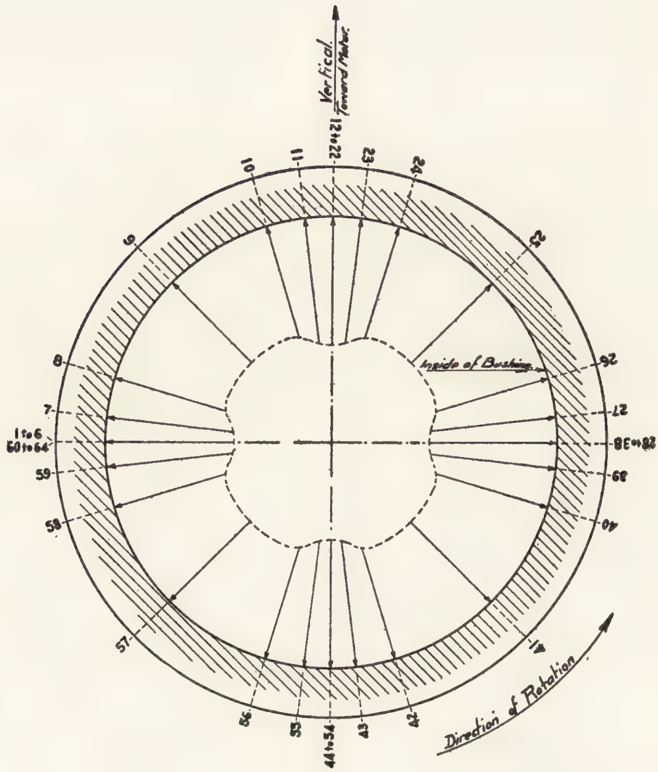


—Fig. 30.—
Locomotive Type C:
Sequence Diagram of
Pressure on Crank Pin
at Maximum Adhesion.

The following general statements will apply to any specific distribution of force:

(1) With the imaginary case of rigid material and no clearance, the system would be indeterminate.

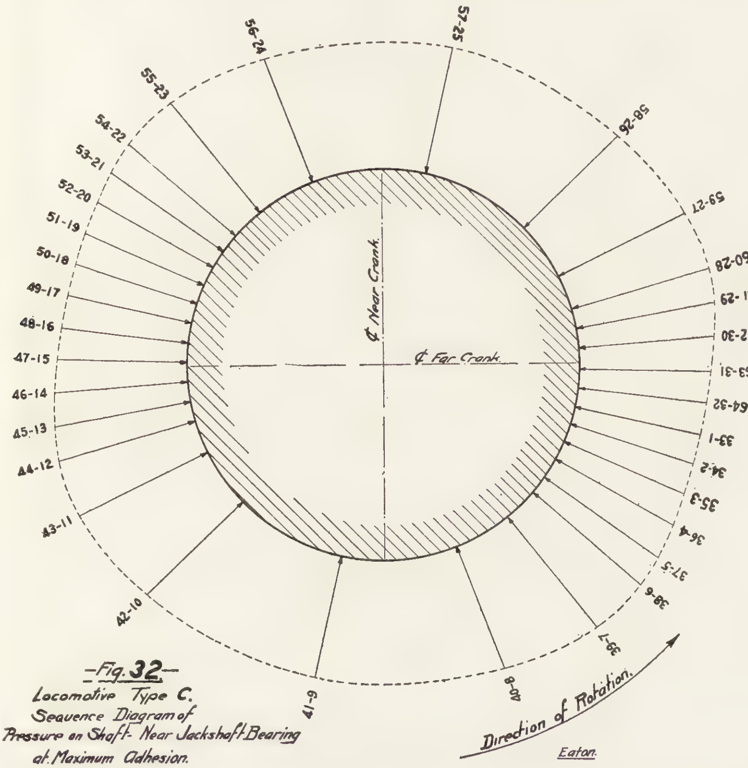
(2) With clearance and flexible material, and while one rod alone is in action, the pressure on that rod will follow the law $P = \frac{100\%}{\text{Sin } \theta}$ (See Fig. 4.)



—Fig. 31.—
Locomotive Type C.
Sequence Diagram of
Pressure on Rod Bushing.
at Maximum Adhesion.

(3) During the four angles of interchange of load between the near and the far rods, the distribution of forces is a function of clearances and deflections.

When direct-current motors drive by means of rods and cranks, it is advisable to provide a mechanical circuit breaker to guard against excessive loads on the rods and the pins in case of a short circuit on the motor during high speed operation. In loco-

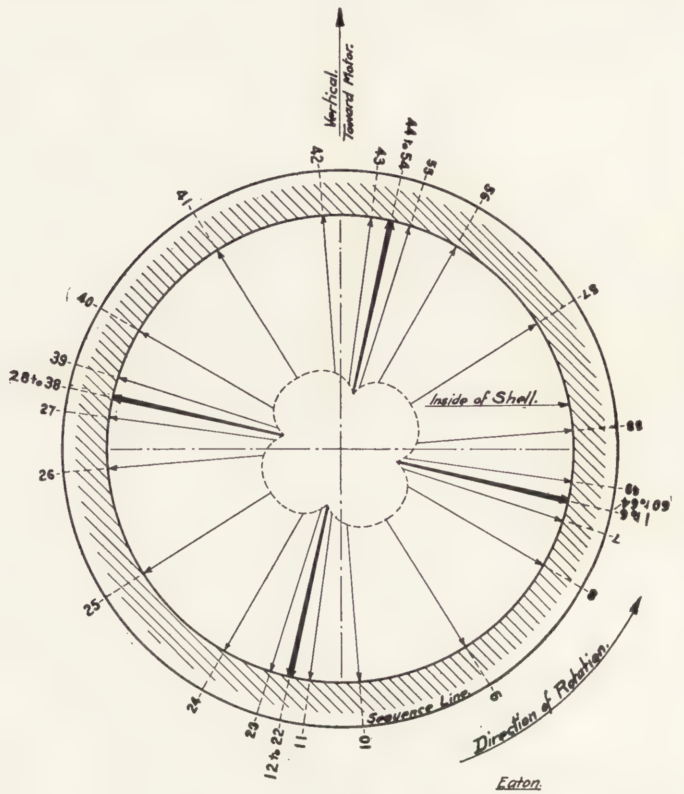


–Fig. 32.–
Locomotive Type C.
Sequence Diagram of
Pressure on Shaft- Near Jackshaft Bearing
at Maximum Adhesion.

motives of this class the rods will be free from resonance phenomena, if so designed that, without excessive stress, they will slip the mechanical breaker when the locomotive is running at its maximum speed.

In any crank-and-rod connected electric locomotive, the entire transmission should probably be designed to stand the maximum pressures that can be applied at any speed, in combination with the strains inherently produced by maximum speed.

The maximum pressure on each rod occurs practically at the point where the corresponding rod on the other side of the locomotive starts to pick up its load. In United States practice, the maximum pressure at 40% adhesion is 115%, and at maximum



—Fig. 33.—
Locomotive Type C.
Sequence Diagram of
Pressure on Shell—Near Jackshaft Bearing
at Maximum Adhesion.

speed is 135%. The maximum pressure will vary as an inverse function of flexibility and of load, and as a direct function of pin and journal clearance and of speed (with motors of series characteristics).

This paper must logically close by again calling attention to the fact that it covers only the static analysis, and that for a complete and thorough appreciation of the sequence of events, as they actually occur in crank-and-rod transmission, a dynamic analysis based upon an accurate static analysis is essential.

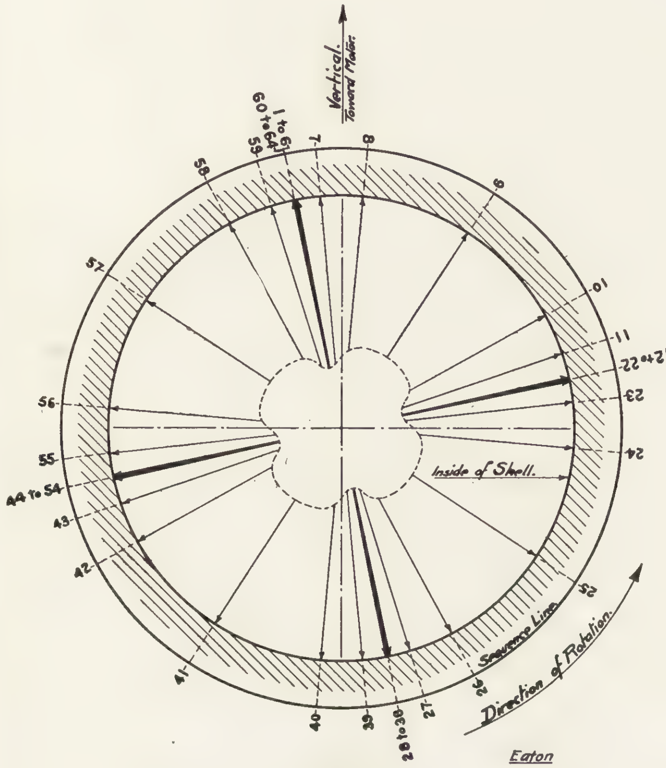


Fig. 34.
Locomotive Type C.
Sequence Diagram of
Pressure on Shell - Far Jackshaft Bearing
at Maximum Adhesion.

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DISCUSSION

Mr. H. J. Kennedy (by letter) expressed the feeling that the title of the paper was somewhat more comprehensive than the subject matter itself, inasmuch as the work was really a study into the forces acting in the bearings and rods of three types of rod-driven electric locomotives, and is confessedly not complete at that, the dynamic analysis not being included. Mr. Kennedy.

He felt that the paper was of interest chiefly to locomotive designers, especially those responsible for the details, but on account of its bearing on one of the leading controversies in electric traction today, he believed that certain points merited especial attention. He referred to the controversy noted in the first paragraph, namely, "Transmission of tractive effort" (he would prefer to say "torque") "from the motors to the driving wheels". The numerous references to foreign journals in the bibliography indicate the endless experimentation which has been carried on in Europe, in devising new methods of rod drives for electric locomotives, some of which he believed, have been failures largely due to "resonance" or sympathetic vibration.

Mr. Eaton's paper shows how he is able to determine the proper sizes of journals for shafts and crank pins, to determine best position for oil holes and for parting the brasses, how he compares the double crank-pin versus knuckle-joint rod design, etc., but entirely avoids the main point of the controversy, viz., which is better for any given class of service, rod drive or gear drive? In Europe they are working all the possible changes on rod drives, not contenting themselves with mathematical analyses, but building actual locomotives and putting them under test; in this country we have stuck to gears, except in the case of two Eastern roads, both engineered by the same firm of consulting engineers.

It might be said by some that the rod drive is better suited to high speed. He had understood that the Pennsylvania Railroad locomotives have run at eighty to ninety miles per hour, but they scarcely get the opportunity to do that in regular service on the short New York terminal section. On the Norfolk and Western, the service is chiefly freight—hauling coal from the mines. The rod drive accomplishes one thing, it puts the center of gravity high and makes the locomotive ride better on curves and makes it less likely to be derailed. But the Chicago, Milwaukee & St. Paul is arranging to avoid the latter danger by stringing together a lot of motor trucks on the Mallet articulation system. Instead of raising the center of gravity, they spread the mass over a long wheel-base.

The rod drive is less noisy than the gear drive, but this usually is not considered of much importance. What he wished to lead up to is, will the author of the paper favor us with a little discussion of his views on the relative merits of rod drive and gear drive? Can he furnish us any statements regarding the comparative costs of maintenance, based upon the experience of the P. R. R. Co. with its rod locomotives?

Mr. Kennedy. A few minor questions might be asked concerning the following points:

Regarding mechanical slipping in the transmission, as protection if motor bucks: how about the use of rubber cushions or metallic springs, between a spider or sleeve and the driving wheel, to ease such shocks. An objection to this device is the very limited angular motion which it permits. Certain locomotives, so equipped, were for a long time under his frequent observation, and it must be said that, early as the design was, the ruggedness of those locomotives was surprising. It was especially noticeable on starting a heavy freight train. At one period the freight trains became so heavy as to necessitate the assistance of a steam locomotive in starting on the up-grade, and there was at times much oscillation, especially when the steam engine slipped its drivers.

Regarding method for determining maximum stress, there is probably a method of determining these points at once, without ''cutting and trying'', by using calculus, but it would undoubtedly involve a tremendous complication of mathematics. Has the author of the paper tried the use of a model, made with adjustable dimensions, and with the rods divided and having dynamometers introduced into them, to indicate the forces acting in the rods? I think a device could be invented to give autographic records, both of the varying stresses and of the positions of the contact points in the bearings. Hardened and ground bushings could be made in the shops to give the exact clearances. A big manufacturing company which can afford to make such profound investigations, could probably afford to develop such an apparatus.

Regarding the statement that the maximum stress will vary as an inverse function of the load, I would suggest that some explanation be given why the variation is inverse and not direct, also stating in what terms the load is expressed.

The author states that ''As far as he had been able to learn, there has never been a knuckle-pin failure on an electric locomotive in the United States''. Would the author please state where, in the United States, the knuckle pins that might have failed have been operating? If he was correctly informed, all the P. R. R. New York terminal locomotives are like type A, and have no knuckle pins. He desired to express the hope that Mr. Eaton might be led to express some opinion regarding the comparative merits of the three types of locomotives shown on page 16.

Mr. Eaton in replying to Mr. Kennedy said that the sense in which the title of the paper is used is with the accent on the first word. To meet fully the criticisms made by Mr. Kennedy, the title should, perhaps, read ''The Mechanical Problem of the Electric Locomotive whose thorough analysis is most difficult''. Mr. Eaton.

In connection with Mr. Kennedy's request for a discussion regarding ''Rod Drive versus Gear Drive'', Mr. Eaton takes the liberty to suggest that such discussion would be out of place in connection with this paper. The paper is based on the decision being already made to use rod drive in some specific locomotive, and the scope of the paper covers only the discussion of details of the rod drive.

In connection with Mr. Kennedy's discussion of high center of gravity and riding characteristics, he is in error in referring to the improvement in the riding of locomotives on curves on account of the high center of gravity. It has been brought out very frequently that high center of gravity or other desirable features from a tracking standpoint are, broadly speaking, more essential on tangent track than they are on curves, and many designs of locomotives, which have been tentatively considered, have had to be abandoned because of the center of gravity being too high for safe riding on curves.

In connection with the questions regarding rubber cushions on metallic springs in place of a slip clutch, it is unquestionably feasible in many cases to make a device that will operate satisfactorily by any of the three methods. Where space is somewhat congested, and where the clutch is quite infrequently called upon to operate, greater capacity can be installed with the slip clutch design than seems feasible by the other methods. There are, however, more or less successful installations of all the kinds mentioned.

The use of calculus in determining at once the various diagrams without ''cutting and trying'' may be entirely feasible. Attention should be called, however, to the existence of a maximum of over twenty variables, and the fact that in the deflection calculations, the cube is frequently involved, so that the difficulties presented by the strictly mathematical method are very considerably in excess of those presented by the method adopted.

In connection with the building of a model for the determination of graphical records and having dynamometers introduced in the rods, it should be noted that very possibly this could be produced. However, on locomotives recently investigated in which the deflections were actually measured after the locomotive was built, the greatest rod extension, or compression, under the most critical dynamic conditions, was less than 0.030″, and it is evident that a model having dynamometers which inherently involve motion would be of almost inconceivable delicacy if they would register on the basis of such small movements as are involved. It must be realized that the movement of the dynamometers must be so small a ratio of the total movement as to be negligible.

Mr. Eaton. A careful study of the paper will show the reason why maximum stress ratio will be greater at light load than at heavy load.

There is one crank-connected electric locomotive with knuckle-pin rods on the New Haven R. R. There are also a large number of mine locomotives with motors, gears and side rods and there are now the Norfolk and Western locomotives, all with knuckle pins.

Paper No. 139

EFFECTS OF ELECTROLYSIS ON ENGINEERING STRUCTURES.

By

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INTRODUCTION.

Electrolysis is chemical decomposition produced by an electric current. This decomposition takes place in an electrolyte, consisting ordinarily of a salt in solution. Soil when entirely dry practically does not conduct electric current, but becomes an electrolytic conductor when moist, on account of dissolved salts, such as chlorides, nitrates, etc., which are always present. Concrete containing moisture is likewise an electrolytic conductor. Engineering structures of metal in contact with earth or with moist concrete may be corroded and ultimately destroyed by electrolysis in cases where electric currents flow from these structures to earth or to the concrete.

The mass of a metal corroded by electrolysis in a given time depends only on the "current," and, with the current densities and other conditions usually found in practice where engineering structures of metal are in contact with earth, is equal to that calculated by Faraday's law. The applied voltage has no effect on the corrosion, except in so far as it determines the current strength; and there is no "minimum voltage" below which electrolysis does not occur. The rapid corrosion by electrolysis from external currents is usually localized and results in pitting of the metal. Such pitting may in some cases result also from natural soil corrosion, so that the "appearance" of a corroded metal structure does not by itself afford conclusive evidence as to whether or not the corrosion was produced by electrolysis from external electric current.

Commercial irons, steels and cast iron show practically no difference in the mass of metal corroded by electrolysis by a given current leaving the electrode for a given time. It should be noted, however, that in the case of cast iron the oxides of iron resulting from electrolysis, together with the carbon contained in cast iron, remain in place, leaving the form of the iron structure unaltered, but with little mechanical strength. In the cases of wrought iron and steels the oxides of iron resulting from electrolysis usually pass to the surrounding earth.

Electrical distribution systems which are grounded at two or more points will, by the law of divided circuits, cause currents, called "stray currents", to shunt through the earth between the grounded points, and these stray currents frequently reach underground metallic structures and corrode them by electrolysis. In practice, it is found that the most important sources of stray electric currents, which so endanger engineering structures, are direct-current electric railways, which use the running-tracks in contact with ground for part of the electric circuit.

Alternating currents have also been used for some years past in a number of electric railways employing the running tracks as a part of the electric circuit, and where these tracks are in contact with ground, stray alternating currents through earth are produced. A number of experimental investigations have shown that where an alternating current flows from iron or lead to an electrolyte, such as ordinary natural soil, corrosion from electrolysis may also be produced, but this proceeds at a relatively slow rate, usually of the order of one per cent or less of the corrosion produced by an equal direct current flowing from the metal to the soil. (See bibliography.) With alternating currents, electrolysis is, however, produced at the two electrodes, instead of at one electrode only, as with direct current. So far as the writer is aware, no damage from electrolysis due to such stray alternating railway currents has been reported to this date. This may be due to the slow rate at which corrosion is produced by alternating currents, together with the fact that most of these railways are of relatively recent date of installation. It may also be due to the fact that stray direct currents are nearly always present with the alternating

currents, and the effects of these direct currents may have inhibited or masked the effect of the alternating currents. It is therefore not possible at this time to draw a positive conclusion as to the possible danger from stray alternating currents.

The following are the principal engineering structures which may be affected by electrolysis from stray electric currents:

(1) Electric railway tracks, and iron or steel structures supporting these tracks

(2) Underground lead-sheathed cable systems.

(3) Underground piping systems

(4) Steel foundations of buildings, bridges, etc., and reinforced concrete structures

The effects of electrolysis on these structures will be briefly discussed under each of the above headings. These notes are based on American practice and the cited examples refer to American installations. While a large amount of work has been done in America during the past decade in applying remedial measures for the protection of structures from electrolysis, nearly all of the information relating to this work exists only in private reports and is held confidential. This is due largely to the fact that in many cases electrolysis is a subject of controversy between different interests; the interested companies therefore naturally object to making public the results of such measures as have been applied to their systems. It is also partly due to the fact that the effectiveness of remedial measures applied to affected structures can, in many cases, be determined only after years of trial. For this reason, most of the examples given in the following are based on the writer's personal experience and on information obtained by him through direct inquiry. In many of the cited examples the locations of the installations are not given, because the writer was not at liberty to do so. It is believed, however, that the information given is sufficiently complete to fully illustrate the measures which have been applied and the results which have been obtained.

A brief statement of the status of electrolysis in Great Britain and Germany is also added. To the paper is appended

a bibliography giving references to the more important published papers on electrolysis.

EFFECTS OF ELECTROLYSIS ON ELECTRIC RAILWAY TRACKS AND ON IRON OR STEEL STRUCTURES SUPPORTING THESE TRACKS.

Where the running tracks of electric railways are used for part of the electric circuit of the railway, and these tracks are in contact with ground, currents will shunt through the earth from these tracks. Where this current flows from the rails to earth corrosion of the rails from electrolysis is produced. Spikes and metal ties which are in contact with the rails may likewise be affected by electrolysis. In most practical cases this current flows from rails to earth over such a widely scattered area that the current density at the points of leaving is quite small, and the corrosion of rails from this cause is correspondingly slow. In such cases the rails usually require replacement from head wear, or for other reasons, before they require replacement because of the corrosion by electrolysis. Certain cases have been found, however, where severe corrosion by electrolysis was produced not only of the rail bases, but also of the spikes fastening the rails to the wooden ties. In these cases the soil or ballast in contact with the rails was relatively wet, the worst cases being found where salt water was present. In such situations every precaution must be taken to increase as much as possible the resistance from the tracks to earth. If this does not accomplish the desired result, the voltage drop in the tracks must be reduced, so that the potential difference between tracks and earth is also reduced.

The principal iron or steel structures supporting electric railway tracks which may be affected by electrolysis are elevated and tunnel structures. Where the construction is such that current can reach these supporting structures from the tracks, such currents may shunt from the supporting structures to earth and cause damage from electrolysis at the points of leaving.

Elevated railway structures are generally low-resistance metallic conductors, and have in some installations been used

as conductors for the return current. For this purpose the tracks are connected to the structure at various points along the route by copper tie cables, and the structures and tracks at each substation are connected by return feeder cables to the negative bus-bar. Where necessary, joints in the structural steel are bonded by copper bond cables. In one large installation of this kind it was found that comparatively large currents were shunted by way of the steel columns and footings through the earth and on to underground pipes and cable sheaths, with resulting damage to these pipes and cables from electrolysis wherever these currents flowed from these pipes and cables to earth to return to the structure. It was also found that the pillar footings of the elevated structure from which current was flowing to earth were being seriously corroded by electrolysis, requiring the repairing of many of these footings. In this installation the trouble was remedied by removing all connections from the steel elevated structure to the running tracks and to the negative bus-bar, including also many accidental contacts which were found to exist between the rails and the structure. As the running tracks are supported on wooden ties and there is no ballast, the structure is now substantially insulated from the electric circuit of the railway. The additional conductance required for the return circuit is supplied by bare negative feeder cables placed on the wooden ties between the tracks, which affords substantial insulation of these feeders. Connections are made between structure and tracks through suitable resistances at neutral points for the purpose of preventing the production of excessive potential differences between running tracks and structure under abnormal conditions which might arise. These neutral points were located where the running tracks are substantially at the potential of the earth, so as to avoid current flow between tracks and earth under normal conditions.

Underground and under-river tunnels often consist of cast-iron shells, made in segments, usually two feet (0.6 m.) or so in length and a part of the circumference in width. These segments are bolted together, and frequently interior grooves at the joints are calked with lead or other packing material. The resistance of such a tunnel structure is largely determined by

the resistances at the surfaces of contact between the segments, and therefore varies within wide limits, and may be relatively high. A number of resistance measurements made by the writer of such cast-iron tunnel structures, having a cross-section of approximately 1250 square inches (8060 sq. cm.), showed resistances varying from 0.0002 to 0.01 ohm per 100 feet (30.5 m.) of tunnel structure, which is, approximately, from 5 to 300 times the resistance that would be obtained with continuous metal of the same cross-section. Where the tracks and structure are metallically in contact the latter acts as an earth plate of enormous area, with a potential difference between points on the plate equal to the voltage drop in the tracks in contact with the structure. Current directly proportional to this voltage drop will, therefore, shunt through earth from this structure, with resultant corrosion of the structure by electrolysis.

The New York Central Railroad operating within the City of New York was electrified in 1906 and uses a 660-volt direct-current third-rail system, with the track rails for the return circuit. About two years after beginning electric operation it was found that corrosion from electrolysis had occurred in the rails and spikes in a wet section of the Park Avenue tunnel on Manhattan Island. To cure this, drains were placed under the tracks in order to keep the ballast in contact with the ties dry, and thereby to increase the resistance from tracks to earth. This has entirely eliminated the trouble, as shown by extensive tests. From 110th Street north to the Harlem River this railroad is carried on a steel elevated structure, on which the rails are supported on wooden ties resting on stone ballast. As this structure is a low-resistance conductor, precautions have been taken to prevent metallic contacts and to maintain as high a resistance as possible between the track rails and the steel structure, thus preventing the flow of current to earth through the column bases and eliminating electrolytic dangers.

In future constructions of iron or steel elevated and tunnel structures for electric railways, every precaution should be taken to prevent metallic contacts between tracks and structure, and to maintain as high a resistance between tracks and structure as possible. This will safeguard the structure, and,

in certain cases, also the rails, against corrosion by electrolysis. Where desirable, connections between structure and tracks, through suitable resistances, may be made at neutral points in order to avoid excessive potential differences between tracks and structure. These connections, however, should not under normal conditions carry substantial currents. Where, in existing constructions, the resistance between structure and tracks is low and cannot be adequately increased, and where considerable currents shunt through structure and earth, the most practical way to reduce this shunting current is to reduce the track voltage drop.

EFFECTS OF ELECTROLYSIS ON UNDERGROUND LEAD-SHEATHED CABLE SYSTEMS.

Lead-sheathed underground telephone, electric light and power cables are most commonly carried in underground conduits of vitrified clay, concrete, fibre, or wood. As the soil in which these conduits are buried is more or less wet, moisture will to a greater or less degree get into the ducts and thereby produce electrolytic contact between earth and the lead sheaths of the cables. As these lead sheaths are relatively thin and as the electrochemical equivalent of lead is nearly four times that of iron, these lead-sheathed cables are very sensitive to the electrolytic effects of stray currents reaching them. Wherever, therefore, such lead-sheathed cables are in underground conduits in localities where substantial stray electric currents are present, it is generally found necessary to provide some measures for protecting these cables against corrosion and ultimate destruction by electrolysis. In manholes the cables are generally supported on iron brackets. It has sometimes been found that currents flow from earth through these iron brackets to the cable sheaths. This has been prevented in some installations by placing porcelain supporting blocks between the brackets and the cables. The resistance between earth and the lead cable sheaths in ducts can be increased by constructing the ducts so as to be as waterproof as possible, and, also, so as to drain towards the manholes. It is also important that the manholes be drained, wherever this can be done at reasonable cost. The writer has found one case where manholes had been

allowed to remain partly filled with water, thereby maintaining the cables submerged, and where rapid electrolytic destruction of the cable sheaths in the manholes resulted, in districts where these sheaths were positive to earth.

The most commonly used method of protecting lead cable sheaths is to "electrically drain" the sheaths to the return circuit of the electric railway, so that the current is taken off by metallic conduction and is thus prevented from leaving electrolytically and thereby damaging the cable sheaths. Where "electrical drainage" is employed, it is important that all of the cable sheaths in the conduit system be connected to the drainage cable; and, also, that the cable sheaths in the manholes be metallically connected together by a copper strap or bond wire. This is necessary in order to prevent considerable potential differences between the sheaths of the cables in adjoining ducts, which could cause currents to flow between the sheaths of these cables and to corrode them by electrolysis.

Drainage connections from cable sheaths should ordinarily not be made to tracks, because a high-resistance joint, or joints, developing in the tracks may destroy the effectiveness of the drainage connection and, in fact, may cause current to flow "to" the cable sheaths instead of "from" them. Such drainage connections should preferably be made either directly to the negative bus-bar or to a negative feeder cable connecting to the negative bus-bar. The object of drainage connections is to render the cable sheaths, throughout, slightly negative to surrounding earth and to other grounded structures. If such a drainage connection is found to render the cable sheaths more negative than is necessary for protection, so that the sheaths are "overdrained", it is desirable to insert a resistance in series with the drainage connection, and to adjust this resistance, and, thereby, the current drained, until the cable sheaths are only slightly negative. In the case of power cables, it is also objectionable to drain an excessive current from the cable sheaths, because this current will heat the cable sheaths and impair the carrying capacity of the cables. If a cable sheath is rendered highly negative to neighboring structures, such as pipes, this tends to set up current flow from the pipes to the cable sheath, causing corrosion of the pipes by electrolysis. In

practice, it is very frequently found that cable sheaths are overdrained, rendering them a source of serious danger to underground piping systems, and trouble from electrolysis of service pipes is commonly experienced where these cross overdrained cables. Such overdrainage is often due to the employment of a larger drainage cable than is required at the time, in order to provide for future growth. In such cases a suitable resistance should be inserted in the cable drainage connection, which can be readily adjusted when changes in the railway load make this necessary.

It is preferable to carry a cable drainage connection directly to the railway substation. An ammeter and a knife switch should then be connected in such a drainage connection, and readings of the ammeter noted at least once every day, so that if abnormal conditions develop, they can be reported and the cause determined. Where drainage connections are made to a substation supplying an interconnected system, which substation is periodically shut down, the drainage circuit must be opened whenever the station is shut down. Local conditions may make it necessary to make drainage connections to a part of the electric railway circuit whose polarity at times reverses with reference to the cable sheaths. In such a case an automatic switch is inserted in series with the drainage connection to keep the drainage circuit closed whenever the cable sheath is positive, and to open this circuit whenever the cable sheath is negative to the drainage contact. In this way current flow from the railway circuit to the cable sheath is automatically prevented. Such automatic switches, though commonly used in situations of this kind, are found in practice to require considerable attention, and it is, therefore, preferred to make drainage connections to points in the electric railway circuit which are at all times negative to the cable sheaths.

Insulating joints in the lead sheaths of cables have been used in some special cases as protection against stray currents, but these joints must only be used with caution, so that potential differences sufficient to harm the sheaths may not be set up across the joints. Such insulating joints in cable sheaths should, wherever possible, be located in relatively dry places. In some installations insulating joints have been used on indi-

vidual cable runs in the positive area for the purpose of breaking up the electrical continuity of the lead sheaths and stopping rapid localized destruction from electrolysis, but these joints, in such situations, will not generally afford permanent and complete protection, and such insulating joints are not generally applicable to cable networks. Special cases arise, however, where insulating joints may be used to prevent current from reaching the sheaths of cable systems. It is found in practice that where an underground cable network has laterals into buildings, considerable currents frequently flow from pipes to the sheaths of the laterals through accidental metallic contacts in the building, and thence to the cable system. Such current flow to the cable system is most effectively stopped by introducing an insulating joint in the sheath of the cable lateral or in the pipe service inside of the building. It is, in fact, the practice of a number of large telephone companies to install insulating joints in the sheaths of all laterals inside of buildings for this purpose.

Where laterals or sections of cables connecting to the main cable system are carried in iron conduits in negative districts, it is sometimes found that considerable current flows from earth to the iron conduits and thence to the cable sheaths, which current is delivered to the sheaths of the cable system. Such current flow can generally be stopped by introducing an insulating joint in the sheath of the cable where it leaves the iron conduit and before it is connected to the main cable system. The writer has found a case of this kind where laterals from a cable system to arc lamp poles were carried in iron conduits, and where considerable current flowed from earth to the conduits and thence to the cable sheaths. Insulating joints were installed in the sheaths of each of these arc light laterals in the manholes from which the iron pipe conduits were laid, and this current flow to the cable system was thereby stopped.

In certain localized sections of a cable run it is sometimes found that considerable current flows to the cable sheaths. A common example of this is where a cable crosses a steel bridge in an iron conduit, and where the conduit is in metallic contact with the structure of the bridge and through this with electric railway tracks on the bridge. In such places considerable cur-

rents may be caused to flow from the tracks through the bridge structure and the iron conduit to the cable system. In order to stop this flow of current to the cable sheaths, insulating joints have been installed in the cable sheaths on each side of the bridge. The outer ends of the cable sheaths may be connected by an insulated copper cable where necessary to prevent the existence of a dangerous potential difference across them.

A simple and cheap construction of insulating joint for lead cable sheaths, which is extensively used, consists in cutting a narrow band of lead out of the sheath and covering the break with a suitable insulating material so as to prevent entrance of moisture.

In future installations of underground cable systems precautions should be taken to prevent electrical contacts with other metallic structures from which currents may flow to the cables. In building laterals, insulating joints should be installed in the cable sheaths directly inside of the building wall. The cable ducts should also be constructed so as to be as nearly waterproof as possible and should slope so as to drain to the manholes, and the latter should be drained to sewers wherever practicable. For main cable runs insulating joints may be installed in special cases to break up the electrical continuity of the lead sheaths, but such joints must be installed only with great caution, and only where they do not cause the sheath on one side of the joint to become dangerously positive in potential to surrounding earth. Insulating joints cannot be generally applied to the sheaths of cable networks.

EFFECTS OF ELECTROLYSIS ON UNDERGROUND PIPING SYSTEMS.

Underground piping systems for the transmission and distribution of gas, water, oil, and similar materials, consist of lengths of iron pipe joined together with screw couplings, lead or other forms of joint. Screw coupling joints generally have a very low electrical resistance, comparable to the pipe itself. Cast lead or lead wool joints have an electrical resistance which is equivalent to from a few feet to several hundred feet of continuous pipe, so that the resistance of the lead joints in a pipe line is usually much larger than the resistance of the pipe itself.

Cement joints generally have a very high resistance, compared with the pipe, so that they may be classed with insulating joints.

Attempts have been made to protect underground pipes from electrolysis by insulating them from earth by paints or dips. Practical experience as well as a large number of tests have, however, shown that no dip or paint will permanently protect a pipe against electrolysis in wet soil. The first difficulty is to apply the paint so as to form an absolutely perfect coating, and the second one is to prevent mechanical damage to the coating during shipment and installation of the pipe. Experience further shows that even where coatings of paints or dips are apparently intact, electrolytic action is not always prevented, and, in fact, very serious electrolytic pittings have been found under apparently good coatings. It has been found that in most cases the applied coatings have either been completely destroyed by the effects of the wet soil and the electric currents, or defects in the coating have developed, causing concentrated corrosion at such defective spots. Where it is attempted to apply a heated material like pitch or asphaltum to a cold pipe, it is impossible to completely cover the pipe. Pitch and similar compounds have been applied to pipes with wrappings of jute or of some similar material. A number of layers can be applied in this way so as to build up any desired thickness of insulating covering. Such covering if sufficiently thick will afford protection against electrolysis, provided that it is mechanically perfect. The great difficulty in practice is to install such covering without leaving defective spots through which moisture will have access to the metal of the pipe.

Pipes, where positive to earth, which are covered with imperfect insulating coatings, or coverings exposing bare spots of metal, are in much greater danger from electrolysis than are bare pipes, for the reason that the stray currents will leave only from these bare spots, and here produce concentrated corrosion. The writer has seen cases where a pipe coated with an imperfect insulating covering was pitted nearly through in one year, whereas a bare pipe in the same locality was very much less affected, because the corrosion was distributed over a larger surface.

One form of insulating covering which appears to afford

certain protection is a layer of one to two inches (2.5 to 5 cm.) of a material like coal tar pitch, parolite, or asphaltum, of such a grade that it is not brittle, and so will not crack, but yet is hard enough to remain in place. The best way to apply such a layer is to surround the pipe with a wooden box, support the pipe upon creosoted blocks of wood or upon blocks of glass, and then fill the space between the box and the pipe with the molten material. When applying this material great care must be exercised to avoid getting stones or dirt into the mixture, and also to avoid leaving bare spots on the pipe. The cost of carrying out such an installation is prohibitive, however, except in very special cases, such as that of service pipes in very bad localities, or that of very important individual pipe lines of small or medium size. Embedding a pipe in cement or concrete, even if this is several inches in thickness, will not protect it from electrolysis, because damp cement or concrete is an electrolytic conductor.

Current flow on metallic pipe lines can be practically prevented by using a sufficient number of insulating joints. A pipe line laid with every joint an insulating joint has a comparatively high resistance and no substantial current can flow on such a pipe line. It is sometimes possible in the case of individual pipe lines to use comparatively few insulating joints to break up the electrical continuity of the line and substantially protect it from electrolysis, but such joints must be installed only after adequate tests have shown that sufficient current will not leave the pipe on the positive side of a joint to flow to earth and do serious damage by electrolysis. Insulating joints in pipe lines should not be confined to the positive areas, but should be installed in all places along the pipe line where there is any considerable potential gradient in the earth parallel to the pipe. The frequency with which insulating joints must be installed in a pipe line in order to assure reasonable protection from electrolysis depends upon the potential gradient through earth and upon the electrical resistivity of the earth. The effective resistance of a short insulating joint is practically the same as that of a long joint. However, a long insulating joint gives a more even distribution of leakage current than a short joint, and hence a long insulating joint is to be preferred where there

is considerable potential difference across the joint, or where the resistance of the surrounding earth is low. The effect of a long joint can be practically secured from a short insulating joint, by surrounding the joint and the pipe for some distance on each side of the joint with a heavy layer of insulating material. In practice, such insulating joints, in important pipe lines, and the pipe for a distance of from 5 to 25 feet (1.5 to 7.6 m.) on each side of the joint have frequently been covered with a layer of from one to two inches (2.5 to 5 cm.) of insulating compound.

Where small service pipes are endangered by current which flows to them either from the main or from house piping, such current flow can be prevented and the service pipe protected by placing an insulating joint in the service pipe at the main or in the building.

Transmission pipe lines, made up of iron pipes with electrically conducting joints, frequently extend across country for many miles, and such pipes may cross and parallel electric railway lines of the same or of different systems. The writer has investigated a number of pipe lines of this kind and has frequently found that stray currents from the electric railways reaching these pipes have seriously damaged them by electrolysis. It is often found that the stray currents will flow to and from the pipes not only where these are close to electric railway tracks, but also in localities many miles away from such tracks, and in sections of country, like open fields, where there are no other underground metallic structures. Attempts have been made in some of these cases to protect the pipe line by installing insulating joints at a few points in the line, especially at crossings of electric railway tracks. It has generally been found, however, that the pipe on one side of the joint was thereby rendered highly positive in potential to the surrounding earth, resulting in rapid destruction of the pipe on the positive side of the joint, thus causing more acute danger than existed before, when the current left the pipe over a more distributed area. In some cases where large currents were found flowing between long-distance pipe lines and the tracks of electric railways at points of crossing, considerable improvement was produced by employing broken stone ballast and keeping

the tracks out of contact with the ground for several hundred feet on each side of the crossing, thereby greatly increasing the resistance from tracks to earth. In general, however, satisfactory protection of long-distance pipe lines, under conditions where stray currents from electric railways flow to and from them over extended areas, cannot be obtained by any remedial measures which can be applied to the pipes.

It is occasionally found in long pipe lines that large currents flow to and from localized sections of the line where there are many electric railway tracks and where the pipe is relatively close to these tracks. In some cases, the pipe in such localized sections has been protected by insulating joints spaced with sufficient frequency to prevent dangerous voltages across any one of the joints. In other cases, the pipe in such a section has been covered with a thick layer of insulating material, and, as an additional precaution, insulating joints have been installed in the pipe at each end of the insulating covering, so that if any defective spots in the covering should develop, no current can reach the pipe at these spots and produce electrolysis. In an investigation extending over about 100 miles (161 km.) of an 8-inch (20.3 cm.) steel cross-country pipe line, made by the writer, stray currents from neighboring electric railways were found at all points tested. In a section of about 6 miles (9.7 km.) of this pipe line, where it crosses and runs close to a number of electric railway tracks, large stray railway currents were found flowing to and from the pipe and causing serious corrosion of the pipe by electrolysis. In order to protect the pipe in this region against this very acute danger, twenty-six insulating joints were installed at selected points, and portions aggregating a total length of about 3½ miles (5.6 km.) of pipe were also covered with one to two inches (2.5 to 5 cm.) of parolite surrounded by a wooden box, with the pipe resting on rectangular glass blocks. At both sides of this insulated section it was found that neither insulating joints nor insulating covering could be safely applied to protect the pipe without carrying the insulation practically over the entire length of the pipe, which would have been prohibitive in expense. Protection of the pipe here can be secured only by adequate improvements in the electric railway systems.

Where considerable currents leave a relatively short section of pipe and endanger it by electrolysis, this section can be protected by surrounding it with an auxiliary pipe electrically connected to it, so that the current will leave from the auxiliary pipe. This is called ''shielding''.

It is sometimes found that underground pipes and other metallic structures of a gas works receive stray currents from the various pipes which connect the works to outside piping systems. Since stray currents are particularly objectionable here, on account of electrolysis and also possible danger from electric sparks, the entrance of such currents has, in some gas works, been prevented by installing insulating joints in each of the pipes connecting to the works.

In one gas works, which is located on a salt water inlet opposite the railway power station, large stray currents were found flowing through the gas works and endangering not only the piping of the works but also the bottoms of tanks. At the railway power station the negative bus-bar was connected by bare underground cables to the tracks directly in front of the station; and this caused stray currents to concentrate towards this power station, some of which, in their path, flowed through the gas works. In the case of two oil tanks stray currents of considerable magnitude were found to flow to the tanks from the connecting oil pipes and thence to earth; to protect the tanks, insulating joints were installed in these pipes, thereby preventing the entrance of current. The stray currents through the works were later substantially eliminated by disconnecting the bus-bar at the power station from the tracks and from all ground contacts, and installing insulated return feeders to points in the tracks surrounding the gas works, which feeders were proportioned for equal voltage drops. In this way a substantially equipotential zone was set up around the works, and the former tendency for current to flow through the works was removed.

While in a number of American cities electrical drainage has been applied to both the gas and water piping systems as a protection against electrolysis, no complete tests of an extensive electrical drainage system applied to pipes are available, so far as the writer is aware. Such tests as have been published

consist only of current measurements on the pipes and of potential measurements between the drained pipes and trolley tracks. The complete data from which to judge the effectiveness of the system would involve the results of many other tests, particularly of measurements of drop across joints in the pipes, and of measurements of potential difference between the drained pipes and other underground structures.

Electrical drainage was first applied to lead cable sheaths, and the success in protecting cable sheaths in this manner led to the attempts to apply the drainage method also to pipes. There are marked differences, however, between an underground piping system and a lead cable system, which render the piping system much less suited for electrical drainage. The principal difference is that cable sheaths are continuous electrical conductors, while pipes may be more or less discontinuous due to the presence of high resistance joints. Another difference is that the lead cable sheaths are relatively small and are carried in ducts, which are mostly non-metallic, so that only part of the surface of the cables is in contact with earth, whereas underground pipes are buried directly in earth and generally present enormous contact areas to earth. The result is that when electrical drainage is applied to pipes, the currents on the pipes are very greatly increased. This results in danger of current shunting around high resistance joints or leaving the pipe on the positive side of a joint to flow to other structures. One case of this kind is reported to the writer where a 4-inch (10 cm.) cast-iron water main, which was electrically drained to the street railway tracks, was badly pitted, causing a water leak on one side of a sleeve coupling. The pipe for some distance on this side of the sleeve was also badly pitted. In this case the sleeve had undoubtedly developed high resistance and current was leaving the pipe on the positive side of the sleeve.

If the pipe which is electrically drained is one which conveys an inflammable liquid or gas, or if it passes through a manhole or other confined space where inflammable gases may collect, the flow of stray current on the pipe may involve the danger of an explosion or fire, particularly at times when the continuity of the pipe is interrupted for repairs or for other causes.

Many cases have been reported where in interrupting or rejoining or recalking mains, electric arcing was produced. The writer has found that in a number of cities where pipe drainage is employed it is the general practice, when mains are to be interrupted or a joint is to be recalked, to first connect a heavy copper wire across the proposed break, so as to prevent danger from arcing. The writer has also found one case where a high-pressure gas main pulled apart at a joint in an open ditch, and the arc caused by the interruption of the main ignited the gas and made it necessary to shut off the gas from this main, and thereby the gas supply for an entire town, in order to extinguish the flames and repair the break. In this case the gas main was electrically drained to the power station and carried a large current.

In the October, 1914, Quarterly of the National Fire Protection Association two cases of gas explosions are described which were caused by gas leakage from pipes which had been pitted by electrolysis, which pipes were electrically drained.

Where both gas and water service pipes enter buildings, the result of producing large stray currents on the pipes is, generally, also to produce a flow of these stray currents through buildings, the current flowing in on one service pipe, passing to the other service pipe through metallic contacts in the building, and then flowing out on the other service pipe. Such stray currents through buildings constitute a serious fire hazard. In the National Fire Protection Association Quarterly referred to above, a case of this kind is also described, where a gas service pipe showing marked pits from electric arcing with a water service pipe was taken from the cellar of a building. The writer has also seen cases where severe arcing was produced between water and gas service pipes in buildings whenever there was vibration of the pipes.

The complete application of electrical drainage to pipes will involve draining all underground piping systems, and, in fact, bonding together all underground metallic structures affected by the stray currents, in such a way that at every point where different structures come into proximity in earth, they are brought to practically the same potential. If this is not done there will be at such points a flow of current through the

earth from the structure of higher potential to that of lower potential, thus causing corrosion of the former.

When electrical drainage is applied to a single system of underground pipes, without making a complete investigation of the effects of possible high resistance joints, etc., the installation may be made at relatively small cost, and when so applied, it usually relieves the acute danger from electrolysis in the immediate neighborhood where the drainage connections are made. Both of these considerations have served to favor the electrical drainage system. However, a single drained underground piping system becomes a source of serious danger to other systems. If electrical drainage is applied comprehensively to all underground metallic systems, it will not only be found very expensive to install but, likewise, expensive to maintain, because as railway and piping systems are changed the drainage system must be changed accordingly. The large increase in current on underground structures produced by electrically draining them also brings about dangerous conditions at scattered and unknown places, which is a serious objection to this method. As an example, in Pittsburgh, where electrical drainage is extensively applied to the water and gas pipes, it is reported (Proc. The Engineers' Society of Western Pennsylvania, July, 1911) that drainage cables aggregating 17,000,000 cir. mils (86 sq. cm.) in cross-section connect to these pipes from the main railway supply station, and that the current drained from these pipes is nearly one half of the total station current.

In the future installations of underground piping systems in the neighborhood of electric railways, precautions should be taken to minimize flow of stray current to the pipes. To this end the pipes should be laid as far from the electric railway tracks at practicable. Metallic contacts with the tracks, such as may exist at iron gate or similar boxes used in water piping systems, must be carefully avoided. Where the pipes cross steel bridges carrying electric railway tracks in metallic contact with the bridge structure, the pipes should be supported on wooden blocks or otherwise insulated from the metal of the bridge structure. Insulating joints should be installed at the entrance of pipes to car barns, as it is frequently found that the

pipes inside of the barns are in metallic contact with the tracks through the building structure. In special cases of individual pipe lines, insulating joints and, in some cases, also insulating covering of adequate thickness, may be employed in localized sections where conditions are found to be suited to their installation.

EFFECTS OF ELECTROLYSIS ON STEEL FOUNDATIONS OF BUILDINGS, BRIDGES, ETC., AND ON REINFORCED CONCRETE STRUCTURES.

Where steel structural work is in contact with earth or is embedded in concrete which is in contact with earth, it is essential that every precaution be taken to prevent stray electric currents flowing from the steel to earth or to concrete, because corrosion of the steel and ultimate cracking of the concrete may result. Stray current is most likely to reach such steel building structures by means of pipes or cable sheaths entering the structure from underground piping or cable systems. When such structures are located where stray electric currents are likely to exist, it is therefore desirable to make measurements of current on all pipes and cables which enter the building, and, where appreciable current is found, to install insulating joints in such pipes and cable sheaths. In the case of steel bridges carrying electric railway tracks, these tracks are frequently laid so as to be in metallic contact with the bridge structure. Where the tracks are positive in potential to earth, currents may flow from the tracks to the bridge structure and thence to earth by way of the grounded ends or structural steel foundations of the bridge, causing corresponding corrosion of the steel at the points of leaving. The most direct and generally the only practicable cure in such cases is to substantially insulate the tracks from the bridge structure. In all new construction this should be done in order to protect the bridge foundations against possible damage by electrolysis. Where pipes and lead-sheathed cables are carried by the steel bridge structure, this precaution will also prevent current from flowing from the tracks through the bridge structure to the pipes and cable sheaths, which current would endanger the pipes and cable sheaths at points of leaving to earth.

To cause damage to a reinforced concrete structure by electrolysis, an electric current must flow between the reinforcing steel and the surrounding concrete. Such current may be leakage current from a direct-current lighting system or stray currents flowing through the building. The conditions required for producing electrolysis of steel embedded in concrete are such, however, that this can result, in the case of reinforced concrete structures, only in special situations; for example, where there is an excessive voltage drop through the earth at the foundations of the building; or where stray current is brought by way of service pipes or cable sheaths into the building and to the reinforcing steel; or where there is a direct contact between the reinforcing steel and one side of a direct-current lighting system, the other side of the system being grounded. It is, therefore, a wise precaution to install insulating joints in all pipes and lead sheaths of cables which enter a reinforced concrete structure. It has been proposed to protect reinforced concrete structures by making the reinforcing steel electrically continuous throughout, and connecting it to the negative terminal of the source of stray current or of a low-voltage generator. While this would prevent corrosion of the steel by electrolysis, it may result in destruction of the bond between the reinforcing steel and the concrete, which results when current flows from concrete to steel.

The structural steel of the Grand Central Terminal of the New York Central Railroad in New York City extends over an area of approximately 40 acres (0.16 sq. km.). The tracks in this terminal and yard are insulated, as far as possible, from the structural steel. To accomplish this the tracks are carried on wooden ties embedded in concrete or stone ballast, and the latter is well drained so as to be maintained dry. Care is taken to prevent accidental contacts between the track rails and the structural steel. Foreign pipes and lead sheathed cables entering the structure are provided with insulating joints whereby the flow of current into the structure by way of these outside conductors is prevented. Foreign pipes crossing the terminal at street level are carried on wooden supports embedded in sand, which is maintained dry by draining. In addition to these precautions, the voltage drop in the tracks in this

terminal and yard is kept very low by having a substation located directly in the terminal, and by employing large insulated conductors for all negative feeder cables. As a final precaution, the structure is electrically drained to the substation negative bus-bar so as to remove from the structure any possible currents that might reach it, and prevent any possibility of this current leaving through the foundation steel. Frequent periodic electrolysis surveys are made and careful watch is kept of the entire situation in this terminal. Permanent pairs of contacts, five feet (1.5 m.) apart, are installed on selected columns, which contacts extend through the concrete and enable measurements of current flow in the columns to be made. The current drained from the structure is also carefully watched, and when the maximum permitted current is exceeded, an investigation is made and the cause removed.

In all new structural steel construction extending into the earth, it is a wise precaution to install insulating joints in all pipes and cable sheaths which connect to the structure from outside systems, and, in fact, to take every precaution to prevent stray electric currents from reaching the steel structure through metallic connections of any kind.

STATUS OF ELECTROLYSIS IN GREAT BRITAIN AND GERMANY.

In Great Britain the Board of Trade prescribes regulations for electric railways designed to minimize leakage of currents from such railways through earth. These Board of Trade regulations have been in effect about twenty years. The most important of the requirements limits the potential difference between any two points in the uninsulated return circuit to 7 volts. In practice, it is found that British electric railways operate well within the prescribed Board of Trade limits, and it is reported that in many railways the maximum voltage drop in the tracks does not exceed 4 volts. Experience has shown that this affords adequate protection to underground structures against electrolysis, and no remedial measures have been applied to underground pipe or cable systems. So far as the writer has been able to learn, practically no cases of electrolytic destruction of underground structures have been reported in Great Britain.

Tests made on underground pipes in Manchester, England, by J. G. Cunliffe and R. G. Cunliffe (see bibliography), did not show any measurable current on any of the underground pipes tested.

In Germany the subject of electrolysis has been extensively studied during the past decade by a joint committee representing the Deutscher Verein von Gas und Wasserfachmännern, the Verband Deutscher Electrotechniker, and the Verein Deutscher Strassenbahn und Kleinbahnverwaltungen. This committee made extensive tests in a large number of German cities, and, as a result of its study, adopted in 1910 a set of regulations (see bibliography) designed to minimize stray currents from direct-current electric railways. The following are the voltage limitations prescribed by these German regulations: The track network is, for this requirement, divided into an inner and outer, or suburban, district. In interurban lines the districts near villages are designated as suburban. The potential difference between any two points on the uninsulated return circuit must not exceed 2.5 volts, under average load conditions, in the inner district and on a bordering belt two kilometers (6560 ft.) wide; outside of this zone, in the suburban districts, the voltage drop must not exceed 1 volt per kilometer (3280 ft.). Although these regulations have no legal force, they are, nevertheless, recognized as the standard throughout Germany. While these regulations were designed to apply to new systems and to extensions of old systems, a number of existing electric railway systems in Germany have already been reconstructed so as to comply with them.

PROBABLE FUTURE TENDENCIES IN ELECTROLYSIS MITIGATION.

The measures which will probably be applied to future constructions of engineering structures in order to safeguard them, or to aid in safeguarding them, against destruction by electrolysis have already been discussed in the foregoing under the separate headings for the various structures. The writer believes, however, that the principal measure for relieving electrolysis dangers will, in the future, be secured by employing such constructions for direct-current electric railways using the

running tracks for the return circuit, as will minimize stray currents through earth. This will be accomplished by decreasing the voltage drop in the tracks, thereby correspondingly decreasing the voltage drop through earth, and by increasing the resistance from tracks to earth, by the following means, given in the order of their importance:

(1) By increasing the number of direct-current supply stations, in systems extending over large areas, so as to reduce the radius to which any one station supplies current, and also by supplying all of the railways in any locality from one supply station in this locality. The increase in the number of supply stations has been brought about in several American cities through the unification of electric light and electric railway interests, whereby the joint utilization of electric light and railway substations for the supply of the railways has been made possible.

(2) By increasing the electrical conductance of the tracks, through the use of heavy rails, through the use of low-resistance rail joint bonds and cross bonds, and through the interconnection of the electric railway tracks of all systems, where these come close together.

(3) By removing current from the tracks by insulated return feeders, and by maintaining the negative bus-bar insulated from ground at the supply station, in all cases where the voltage drop in the tracks would otherwise be excessive. This arrangement is known as the "insulated return feeder system."

(4) By increasing the resistance between tracks and earth as much as practicable, through draining the roadbed and, on private right-of-way, through maintaining the tracks out of contact with ground except at the ties.

The above railway constructions are already in general use in England and, to a considerable extent, also in Germany, and during the past few years such constructions have also been employed in a number of American electric railways. Many years' experience abroad has shown that such improvements in electric railway construction can be practically carried to a point where stray currents through earth from these railways become negligible. The insulated return feeder system, in conjunction with proper track bonding, usually affords the most

feasible means for reducing track voltage drop in an existing electric railway. In this system, feeders insulated from earth are connected from the negative bus-bar to selected points on the track network. For the best results, these feeders should be proportioned for substantially the same voltage drop under average load conditions. If the tracks are to be connected to the negative bus-bar at the supply station, this must only be done through a resistance proportioned so as to give substantially the same voltage drop as exists in the feeders. This system reduces track voltage drop, and also diminishes the area over which the leakage of current from the tracks takes place. Since the stray currents through earth depend upon the track voltage drop and upon the area over which this leakage occurs, they are reduced in the proportion of the product of these two factors. The concentration of stray current near the supply station is also avoided.

The effectiveness of the insulated return feeder system in reducing stray currents through earth is practically independent of the voltage drop in the feeders, and, consequently, of the weight of copper employed. The most economical feeder sizes are those for which the sum of the fixed charges and the cost of their power losses are a minimum.

The insulated return feeder system is frequently confused with the system of "paralleling the tracks" with return feeders, which has been most commonly used in American electric railways. From the standpoint of reducing track voltage drop the two systems are, however, totally different. With copper feeders paralleling the tracks, the voltage drop in the tracks is reduced only in the proportion that the conductance of the track circuit is increased. For example, an amount of paralleling copper equal in conductance to the tracks could at best only reduce the drop in these tracks to one half. It is therefore evident that where the voltage drop in tracks is high, this system would require a prohibitive amount of copper to reduce the voltage drop to reasonably low values. With the insulated return feeder system, on the other hand, the voltage drop in the insulated feeders does not occur in the tracks nor in the earth, and therefore may be made as high as economy dictates. It should be emphasized that with insulated feeders, the

tracks in the immediate neighborhood of the power supply station should be connected to the negative bus-bar only through a suitable resistance, as a direct connection at this point would practically convert the insulated feeder system into a system with feeders paralleling the tracks, because both ends would then be in contact with earth.

With the insulated return feeder system the power losses are increased over what they would be if the same amount of copper were employed in parallel with the tracks. This increase in power losses is a necessary expense, however, for the purpose of reducing stray currents through earth, and correspondingly reducing injury to underground structures.

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DISCUSSION

Mr. Cook. **Mr. E. W. Cook,*** Assoc. A. I. E. E., (by letter) pointed out that the electrolysis problem is a very complex one, and no fair decision can be reached unless it is constantly remembered that all the utilities involved are necessities of modern life, and that the cost of the service of any one of them should not be greatly increased unless such increase causes a corresponding decrease in the abnormal cost of the service of the others.

The rail-return direct-current electric railway should do all that is practicable from the standpoint of cost of its service to prevent the leakage of stray current from its rails, and the owners of underground utilities should take all the comparatively inexpensive precautions enumerated by Prof. Ganz to make the structures less susceptible to damage by stray current. Under the caption ''Probable future tendencies in electrolysis mitigation'', four measures are given for minimizing the stray-current leakage from the tracks of direct-current rail-return railways, but no mention is made of the use of a modification of the Edison 3-wire system of distribution of power to the cars.

By this system, the rails are only required to carry the unbalanced part of the load just as the neutral does in the familiar 3-wire lighting circuit.

This modification of the 3-wire system has very decided advantages in certain special cases over the insulated negative-feeder system, with or without additional direct-current supply stations. He agreed with Prof. Ganz, that there is no great amount of conclusive evidence regarding the effectiveness of any system installed in this country, owing to the long time usually required for the trouble to manifest itself, but desired to state that one of the largest interurban railways in this country has had a suburban network of tracks, equivalent to about 20 miles of single track, under 3-wire operation for about a year, and after very complete tests made on rail voltage gradients, and overall voltage drops, has recently extended this network to include a total of about 30 miles of single-track equivalent, and is now changing the overhead distribution system for an entire city network, totalling some 50 miles of tracks.

Mr. Warren. **Mr. H. S. Warren,†** Fel. A. I. E. E., (by letter), expressed agreement with Professor Ganz in emphasizing the importance of keeping underground lead-sheathed cable systems free from contact with other underground structures. It is the practice of the Associated Bell Telephone Companies to pay particular attention to this point in order to simplify as much as possible their drainage problem, which, under present conditions, is, at the best, both troublesome and expensive.

Professor Ganz calls attention to the damage that results to other structures when lead-sheathed cable systems are ''overdrained''. While

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caution as to this possibility is fully justified, it may be pointed out that a certain amount of current flow from other structures must be expected wherever this method of protection has to be employed. Lead-sheathed cable systems should, of course, never be overdrained and it is my belief that they are very rarely overdrained. Mr. Warren.

Overdraining should not be concluded simply because at certain times relatively high negative potentials are found at some few points between a lead-sheath cable system and another structure. In rendering lead-sheathed cable systems negative at all times to other structures, which is essential to their protection, it will be found that with the natural shifting of street railway load it is not possible to keep all parts of such systems at all times at the same negative potential with respect to other structures. Since they can never be permitted with safety to assume any positive potential, it means that at certain times various parts of the system are lower in potential with respect to other underground structures than at others. The very nature of the case implies that a condition of equilibrium cannot be maintained unless all the underground structures form a completely interconnected metallic network. In the absence of such a completely interconnected metallic network, there must at times be current flow from other underground structures to the electrically-drained, lead-sheathed cable systems. In other portions of Professor Ganz' paper, reasons that appear to me to be convincing are given which cast considerable doubt on the wisdom of including gas and water systems in any interconnected and electrically-drained network.

These considerations, in addition to the many others given by Professor Ganz in his paper, justify the belief that the logical means of attacking the electrolysis problem is at its source; that is, by providing means that will reduce, if not substantially eliminate, the flow of stray current in the earth. Professor Ganz has in the last section of his paper outlined the means which appear to be the logical ones to accomplish this end. The writer had personally conducted and witnessed tests in this country involving the use of the insulated negative-feeder system, which left no doubt in his mind as to its effectiveness. He had also had occasion to make electrolysis investigations in Great Britain, where this system has been in use for many years, and which furnish conclusive evidence of the fact that where this system is employed the electrolysis difficulty has been practically eliminated.

Paper No. 140

ON THE PRODUCTION OF HIGH PERMEABILITY IN IRON.

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I. BY THE METHOD OF MAGNETIC SHIELDING.*

This part of the present paper deals more particularly with the permeability exhibited by a 3 per cent silicon alloy of iron, known as "Stalloy", over a range of the magnetic induction B from about 0.5 to 100. It is shown that if a ring consisting of laminae of the material is placed within a special magnetic shield and then subjected to a process of careful demagnetisation, the permeability can be largely increased.

The specimen is built up to an axial length of 38.8 cm. of stampings having internal and external diameters of 7.6 and 12.75 cm., respectively, and thickness varying from 0.34 to 0.14 cm.

The shield is built up to a length of 47 cm. of stampings of transformer iron 0.62 mm. thick. The internal and external diameters of each stamping are 30.5 and 40.6 cm., respectively. At each end are discs of soft iron 40.6 cm. diameter, which, together with two square end plates, make up an overall length of 56 cm. The laminae are firmly clamped together by four bolts passing through the end plates. For the insertion of the leading-in wires to the primary and secondary windings on the specimen, a few of the stampings nearest to the end discs have a small piece cut away so as to form a narrow opening into the shield.

The specimen is supported symmetrically within the shield, and their common axis is placed at right angles to the magnetic

* Proceedings of the Royal Society of London A., Vol. 90, 1914, p. 179.

meridian. Throughout the experiments, the ballistic galvanometer has been used. An alternator was used for the purpose of demagnetising the specimen, the frequency being 50. The current was gradually reduced by variation of resistance until the magnetic force H was of the order 10^{-4} C. G. S. units, the alternator being finally allowed to come to rest with its excitation left on.

Reference can now be made to Figure 1, in which the permeability is plotted against magnetic induction. Before being placed in the shield, the specimen was demagnetised from a force of 0.3 C. G. S. units, and experiment 1, corresponding to curve 1, was made. When in the shield, the specimen was demagnetised from a force of 0.59 and experiment 2, corresponding to curve 2, was made. Up to this time it should be noted that the highest force so far applied has been 0.59, and, at the close of experiment 2, the specimen was left magnetised as the result of a force 0.0935, and eight days elapsed before further experiments were made. At the end of this time, a magnetising force 0.8 C. G. S. units, due to a continuous current, was applied, reversed a few times, and removed.

A force of such magnitude as 0.8 applied to a demagnetised specimen has, in ordinary magnetic testing, the effect of causing the magnetic induction corresponding to a given smaller force to be lower than it would have been had the iron been in a demagnetised state originally. In the shield the reverse is the case, as is shown by experiment 3, corresponding to curve 3. Curve 4 was obtained after demagnetising from a force 1.2, and curve 5 was obtained after demagnetisation from a force of 2.97. Then followed a number of experiments on the effect of testing the specimen after varying periods of rest in (1) a magnetised condition, and (2) a demagnetised condition. Curve 17 shows the effect of resting in a demagnetised condition for 13 days, and a rest of 6 weeks gives no further diminution in permeability. Further experiment shows that this high permeability still persists when the specimen is removed from the shield.

The dissipation of energy, due to magnetic hysteresis, corresponding to a given maximum value of the magnetic induction, is considerably reduced by the above method of treatment. The following table gives detailed information obtained from experi-

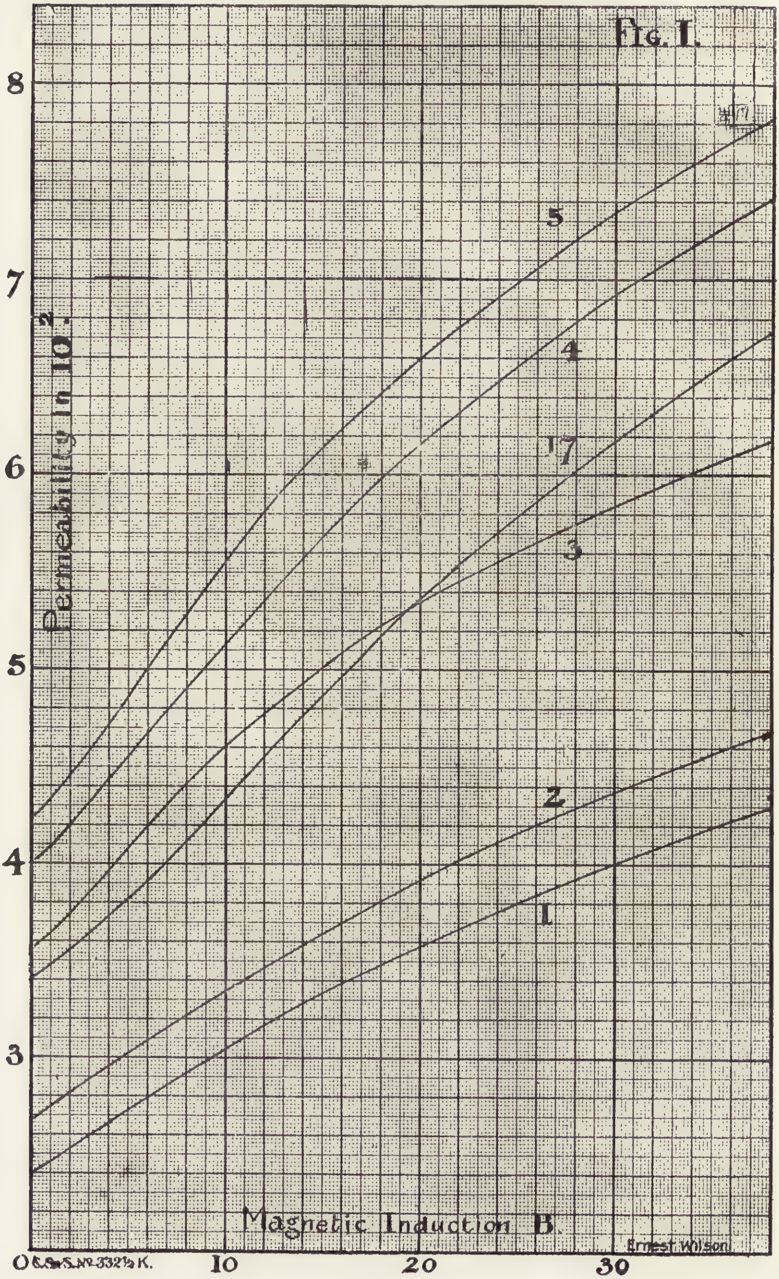
Fig. I.
8
7
6
5
4
3
Permeability in 10²
5
4
17
3
2
1
Magnetic Induction B.
Ernest Wilson
O C.S.&S. Nº 332½ K.
10
20
30

ments 1 and 18, in the latter of which, the material was in the highly permeable state, closely corresponding to curve 4 in Fig. 1.

Experiment	Maximum H	Maximum B	Permeability	Ergs per cycle per cu. c.m.	Coercive Force	Residual Magnetic Induction
	0.000499	0.117	235	....	....	....
	0.000849	0.204	240	....	....	....
	0.00168	0.412	246	....	....	....
1.	0.00420	1.04	248	0.0000190	0.000062	0.018
	0.00843	2.15	255	0.0000723	0.00018	0.038
	0.0179	4.9	274	0.000801	0.00071	0.18
	0.0496	17.2	347	0.0155	0.00417	1.47
	0.0935	41.2	441	0.0974	0.0100	4.55
	0.00168	0.68	405	0.0000031	0.000016	0.0068
	0.00420	1.72	410	0.0000306	0.000058	0.028
	0.00843	3.59	426	0.000279	0.00031	0.13
	0.0179	8.92	498	0.00291	0.0014	0.65
	0.0496	36.4	734	0.0583	0.0063	4.9
18.	0.0935	88.3	944	0.306	0.0138	14.0
	0.191	237	1240	2.1	0.037	47.4
	0.418	1016	2430	39.5	0.170	454
	0.783	4340	5540	449	0.393	3160
	1.62	8210	5070	1300	0.531	6130

II. BY THE METHOD OF HEAT TREATMENT.

In this section the permeability exhibited by iron under the higher forces is studied, more especially the maximum value of the permeability. It has been shown that if a specimen of iron in laminated ring form is allowed to cool through the temperature at which it regains its magnetic properties during the application of a magnetising force, due to either an alternating or continuous current, the maximum value of the permeability can be greatly increased.

(a) Alternating Current.*

In Figure 2 the curve 1 shows the relation between the permeability and magnetic induction in the case of silicon alloy sheet having the following composition: C. 0.06, Mn. 0.13, P.

* Pender and Jones, Physical Review, 2nd Series, April, 1913, Vol. 1, No. 4

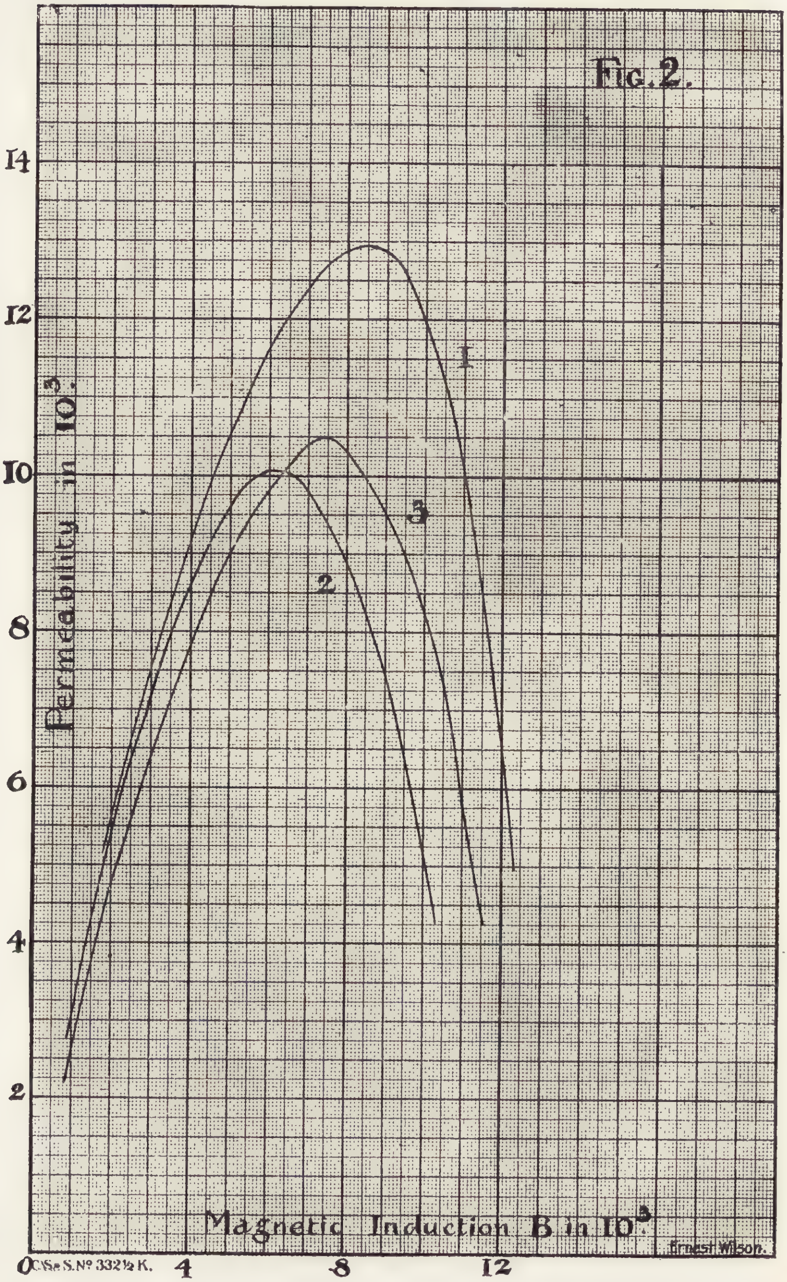
FIG. 2.
14
12
10
8
6
4
2
Permeability in 10^3.
1
2
3
Magnetic Induction B in 10^3.
0
4
8
12
C.W.&S. N° 332½ K.
Ernest Wilson.

0.04, S. 0.02, Si. 3.46. The specimen weighed 2.95 kg., and consisted of 100 stampings in the form of hollow squares, having 7.62 cm. and 12.7 cm. internal and external diameters, respectively. The maximum temperature to which the specimen was raised was 870° C., and the maximum force 18.5 C. G. S. units, due to an alternating current of 60 frequency, was applied to the specimen during cooling from 870° C. to 160° C.

In the case of another specimen containing C. 0.09, Mn. 0.17, P. 0.05, S. 0.03, Si. 3.95, with magnetic induction B 7500, a maximum permeability of 11,500 was obtained on heating to a maximum temperature of 795° C., and applying a maximum force of 29.6 during cooling from 795° C. to 400° C. at 60 frequency.

In the case of low carbon steel, with magnetic induction B 9100, a maximum value of the permeability of 12,100 was obtained by raising the temperature of the specimen to 835° C. and impressing upon it a maximum magnetising force of 18.5 C. G. S. units during cooling from 835° C. to 200° C. After ageing at 100° C. for 865 hours this specimen exhibited a maximum permeability of 10,900.

As regards hysteresis and eddy current loss in watts per lb. at 60 frequency and magnetic induction B 10,000, the 3.46 silicon alloy gave 1.30 as received, and 0.63 after treatment at 870° C. The 3.95 silicon alloy gave 1.55 as received, and 0.60 after treatment at 795° C. The low carbon steel gave 1.28 when in the state of maximum permeability.

The original paper should be studied by those interested in this subject, as it contains much useful information. The loss and regaining of magnetic properties, as the specimen is heated and cooled, shows that these high values of the permeability are not acquired at the high temperatures, but that the permeability more or less gradually rises to its maximum value as the temperature reaches that of the atmosphere. The effect of the initial temperature of magnetisation, as the specimen cools from a given temperature, has also been studied. For instance, in the case of cooling from 800° C., it is shown that the ultimate maximum permeability has a higher value if the magnetisation is applied at 700° C. than if applied at 750° C. Then again, it is shown that the percentage increase in the maximum permeability due to this

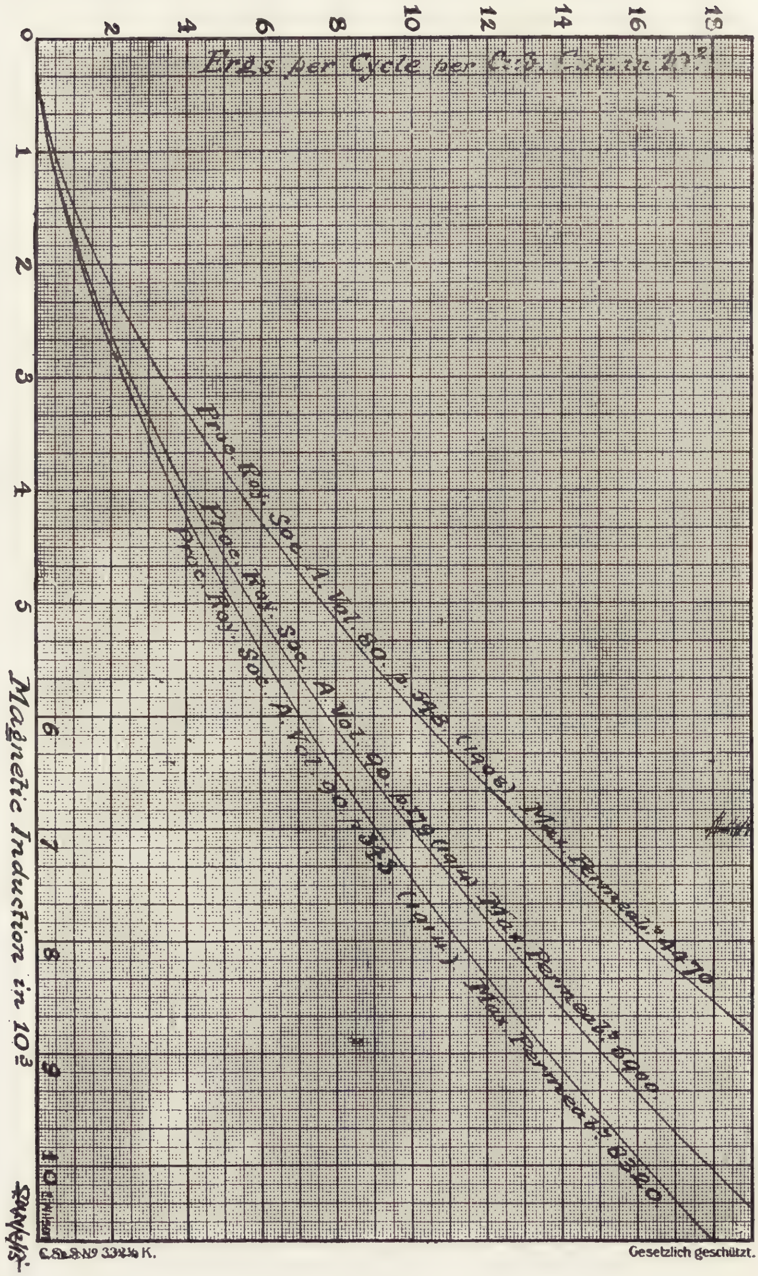
Ergs per Cycle per C.C.
Magnetic Induction in 10³
Gesetzlich geschützt.

Fig. 3.

treatment is greater, the greater the value of the magnetising force, until this reaches a value of about 18, when no further increase is experienced. The authors show how the hysteresis loop is affected by the treatment above described. Their remarks agree with those already made by the Author of this paper, namely, that the diminution in the loss is due to a diminution in the coercive force rather than in the residual magnetism. That is to say, the loop is more upright and narrower.

(b) Continuous Current.*

In Figure 2, the curves 2 and 3 show the relation between the permeability and the magnetic induction in the case of a 3 per cent silicon alloy (the exact composition of the alloy is not known to the Author). The specimen was built up of about 100 gm. of stampings 0.042 cm. thick, each having internal and external diameters of 3.2 cm. and 4.5 cm., respectively. The maximum temperature to which the specimen was raised was in the neighbourhood of 800° C., and it was allowed to cool with a magnetising force, due to a continuous current, applied throughout the whole duration of cooling. In the case of curve 2, the magnitude of this force was 3.12 C. G. S. units, and in the case of curve 3, 14 C. G. S. units. About five hours were required for cooling in each case. It will be noticed that a maximum permeability of over 10,000 is obtained in each case, and that this maximum (as mentioned under IIa) is greater, and occurs at a larger value of the magnetic induction, when the force applied during cooling is 14 C. G. S. units.

As regards the dissipation of energy due to magnetic hysteresis, it has already been pointed out (under IIa) that when in the state of high maximum permeability, it is smaller for a given value of the maximum magnetic induction than in the normal specimen. The same remark holds good with continuous current magnetisation. Figure 3 shows the relation between the ergs per cycle per cu. cm. and the maximum magnetic induction B.

The foregoing remarks refer to material which has been tested in the form of laminated squares or rings, and as iron is largely used in the form of strips which are built up to form the

* Royal Society of London A., Vol. 90, p. 343; also Royal Society of London A., Vol. 91, p. 104.

cores of transformers, etc., it becomes a question as to whether this increased value in the permeability is capable of being produced in and retained by the strips. It may be mentioned that even in the ring form the high permeability is easily lost if the stampings are subjected to severe mechanical disturbance, such as bending. A number of experiments made with straight strips 8 cm. long, 1.5 cm. wide, and 0.053 cm. thick, built into the form of test pieces, by taking a number of them side by side, show that the improvement is not maintained, and that with the ordinary handling which such strips undergo in practice, the specimen is speedily reduced to the normal state.

Paper No. 141

ELECTRIC ILLUMINANTS.

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Commercial electric lighting is only about thirty-five years old and yet a complete historical statement describing the development and growth of all the various types and forms of electrical illuminants that have been used commercially and the apparatus, accessories and equipment necessary for their operation and maintenance would cover a large part of the whole field of electrical engineering; and the principles of Illuminating Engineering would be also largely defined by a consideration of effective, aesthetic and efficient methods for utilizing such illuminants for artificial lighting of all kinds.

Series Open Arc Lamp.

Although the results of the work of many early scientists and inventors, both in Europe and America, made possible the development of electric lighting for practical use, its transition from an unsettled, experimental state to that of a promising and successful commercial aspirant was brought about by the invention and exploitation, in 1878, of the series direct-current arc lamp, utilizing the shunt principle for regulation. This event thus virtually marks the birth of the electrical industry. Previous to this time various arc lighting sets had been made, consisting mostly of dynamos designed to operate a single lamp each, which were used quite successfully for lighthouses, for exhibition and experimental purposes, and in some few cases for store and street lighting.

The first series lamps were operated from constant-current D. C. arc machines originally built to run six lamps in series, then ten, sixteen, etc., until ultimately they were made in sizes

capable of carrying one hundred and twenty-five 9.6-amp. lamps at an arc voltage of about 45 volts per lamp. Many different types of lamps were built, some differential, some plain shunt, some with ''floating'' mechanisms and others of the fixed arc-gap type. There was an early controversy between the advocates of ''short arcs'' and ''long arcs'', the point being that more of the former could be operated in series with a given voltage. The ''short arc'' lamps were wound for about 20 amperes and arc voltage was adjusted for about 25 to 30 volts. They were unsteady in operation, made a sizzling, frying noise and consumed the electrodes rapidly, while due to the high current the line losses with this system were excessive. The ''long arcs'', which were mostly of the ''floating'' arc type, operated at about 9.6 amperes, 45 to 50 volts at the arc. They were quieter than the other type, although slightly bluer, gave steadier light, were more economical of electrodes, and in a few years entirely displaced the ''short arc'' type. Two other terms that were commonly used were ''full arcs'' and ''half arcs'', the former name referring to the 9.6-amp. size of lamp and the latter to a 6.6-amp. lamp that was used where smaller units were desired. These two sizes of arcs were originally rated as 2000 and 1200 candle-power, respectively, with the idea of indicating apparently the maximum candle-power. Since these values are nearly double the correct maximum candle-power, the terms ''nominal 2000 c.p.'' and ''nominal 1200 c.p.'' were afterwards used in referring to these original ratings. The actual mean spherical candle-powers of these lamps are about 450 for the 9.6 amp. and 280 for the 6.6 amp., dependent upon carbons, adjustments, etc.

Alternating Current Open Arc.

Attempts were early made to run arcs in series on alternating current. In fact the so-called Jablochkoff candles that were exhibited at the Paris Exposition, 1878, were a type of alternating-current arc lamp without regulating mechanisms, operated several in series. After the introduction of the D. C. series arc system had become well established, attempts were made to operate A. C. open-arc lamps in series from constant-current generators and by means of individual transformers. Due to lamp troubles, poor light and noisy operation, particularly on

account of the imperfect carbons in use at that time, such lamps did not prove successful.

During the first ten years of commercial electric lighting, however, the growth was phenomenal, and by the year 1890 statistics show that there were in the neighborhood of 250,000 series D. C. open-arc lamps, used mostly for street illumination, installed in the United States alone.

Incandescent Lamps.

In the meantime, or only a year or two behind the arc lamp, small unit electric lighting had been accomplished in 1880 by the simultaneous commercial introduction of the incandescent lamp and the constant-potential direct-current dynamo and system of operation. About the year 1887 the system of alternating-current distribution by means of multiple transformers was introduced in America (although it had been under development abroad since 1883) and incandescent lamps were also operated on such circuits. The first incandescent lamps exhibited in America took about 7.6 watts per candle, but were soon improved so that they consumed 5.8 w.p.c. Experimental filaments were then made by carbonizing all sorts of materials, the most satisfactory proving to be those constructed from strips of paper, silk, cotton thread and bamboo fibre. The two latter materials ultimately became standardized by different manufacturers for the commercial production of incandescent lamps, an especially perfect variety of bamboo, in fact, being used for fifteen years before it was replaced by filaments made by the "squirting" method. The so-called "treating" process whereby raw carbon filaments can be made more uniform and stronger by raising them to incandescence in an atmosphere of hydrocarbon gas had been known for many years, but was not adopted by all incandescent lamp manufacturers until the early nineties. Although used first because filaments were thus made uniform, it eventually developed that the process produces a surface that can be operated at higher temperature and consequently at better efficiency than is possible with "raw carbon".

At the end of the first decade of electric lighting, therefore, the general practice was the use of 9.6- and 6.6-ampere series D. C. open-arc lamps for street and other outdoor lighting and for the illumination of large interiors; while incan-

descent lamps taking from 4 to 4½ watts per candle were used in immense quantities for operation on 110-volt circuits for interior lighting of all kinds, and to some extent for series connection. Most of the important installations were for direct current, although a number of alternating-current stations had been started. These latter were nearly all small and located in suburban localities where the economical advantage of A. C. distribution was a prime factor; but due to poor regulation and the fact that alternating-current arc lamps were not then successful, these first A. C. installations were not generally considered entirely satisfactory. Prior to this time, although there had been various more or less satisfactory systems introduced for operating incandescent lamps in series, there had been no commercially successful arc lamps produced for operation on constant potential "incandescent" lighting circuits.

Constant Potential Arc Lamp.

In 1890 lamps for this purpose designed to operate at about 8 amperes, 45 volts at arc, two-in-series on 110 volts D. C., 4- or 5-in-series on 220 volts D. C. and 8- or 10-in-series on 500 volts D. C., were brought out and proved very popular. About 1893, lamps of similar type for A. C. multiple connection were introduced commercially. These lamps were used with individual transformers and could thus be operated either in series or in multiple from the then standard 1000-volt A. C. circuits or from incandescent-lamp circuits, if desired. When used on the latter circuits, it was the practice to run them one, two or three together in connection with so-called economy coils (auto-transformers). These lamps were generally wound for 15 amperes and adjusted for about 33 volts at arc. Due, however, to the noise of the mechanisms and the humming of the arcs, A. C. open-arc lamps never made much progress in this country.

The '90's was a time of great improvements, particularly in A. C. apparatus and in incandescent lamps. There were no radical changes in the latter except the universal adoption of the "squirting" process of making filaments and the introduction of many refinements in the structure and manufacture that made the efficiency and life more uniform.

Enclosed Arc Lamp.

In 1894 the enclosed carbon-arc lamp was first exploited and marked the beginning of improvement of domestic carbon electrodes for arc lamps. The essential feature of this lamp was the fitting of a small glass bulb around the arc so as to only allow the entrance of a minimum amount of oxygen to the arc chamber, thus causing the arc to burn in an atmosphere of nearly inert gases. This enclosure of the arc has a marked effect upon the character of the arc itself, increasing its most favorable operating voltage on D. C. from 45 to about 80 and its length from 1/8 in. to about 5/16 in. to 3/8 in.; while on alternating current, the arc voltage is about 72. The arc is much steadier, being shielded from air currents, and the electrodes consume very much less rapidly, lasting for 100 to 150 hours per trim of electrodes as against 10 to 18 hours with open-arc lamps. As with the open-arc lamp, more than 90% of the light is emitted by the incandescent carbon tips and very little from the arc itself. Due to the restriction of carbon combustion and to the lower current density at the electrodes, the crater of the enclosed arc is smaller at equal arc wattage than that of the open arc, and the intensity and amount of light much lower. The light from it is bluer in color than that from the open arc, caused apparently by the relatively larger amount of light radiated by the carbon vapor of the longer enclosed arc.

Although the enclosed-arc principle was first determined in connection with lamps on D. C. series arc circuits, the initial field for this lamp seemed to be for use in multiple on constant-potential incandescent-lamp circuits, and this type of arc lamp, therefore, early gained the name "incandescent arc". It became very popular in America on account of its long life and consequent low trimming labor and electrode costs. It was made for use on both D. C. and A. C. 110-volt lighting circuits, being commonly wound for 5 amperes on D. C. and for 6 or 7½ amperes on A. C., and was also adapted for series D. C., but at a current of 6.6 amperes instead of 9.6 amperes as with open arcs, so as to maintain the terminal watts about the same. Lamps of this type were designed for use singly and two-in-series on 220-volt D. C. constant potential, and 4- or 5-in-series on railway circuits.

Series A. C. Street Lighting System.

During the years 1895 to 1897 very few A. C. arc lamps were in use, but about the year 1898 the constant-current transformer and the inductive-type regulator were brought out, introducing the era of the series A. C. enclosed carbon-arc street lighting system. In spite of the very marked lower efficiency and intensity of the A. C. enclosed type of lamp, this system within ten years—due to the lower trimming expense, freedom from sparks and more attractive light distribution for street lighting of the lamp and the fact that a number of circuits could be run from a single generator, thus eliminating the necessity of operating many separate arc machines—almost completely displaced in America the series open-arc system of street lighting. Circuits of 25 and 50 lamps were first operated, but ultimately many installations of 75 and 100 lamps in series were made.

Foreign Practice.

In Europe, where the cost of power was higher and both labor and high quality carbon electrodes were much cheaper than in this country, the comparatively inefficient enclosed-arc lamp never gained a foothold except to a limited extent in England. Due also to prejudice against the high voltage necessary for series circuits, the practice abroad developed the use of open-arc lamps burning two-in-series or even three-in-series on 110-volt D. C. constant-potential circuits, or five- or six-in-series on 220 volts. These lamps were so highly perfected, and the carbon electrodes used were so uniform and refined, that very steady operation was secured with resulting white light at attractive efficiency. By using very soft carbon electrodes, which produced a large amount of conducting vapor, open-arc lamps for multiple connection on low-voltage alternating-current circuits were produced that ran very quietly and gave satisfactory illumination.

At the end of the second decade of electric lighting, multiple and series enclosed-carbon arc lamps for both A. C. and D. C. were being used and installed in large numbers. Incandescent lamps of the standard 110-volt 16 c.p. rating had a specific consumption of 3.1 watts per candle and series incandescents took 3.5 w.p.c. It is interesting to note that up to this time carbon

was the only material that had ever been used commercially for incandescent-lamp filaments or for arc-lamp electrodes, and the useful light produced had been entirely due to "incandescence".

Nernst Lamp.

With the beginning of the third decade, three widely different forms of illuminants were being developed that used other material than carbon for emitting light; materials that due to the phenomena of "luminescence" and of "selective-radiation" produce light more efficiently than carbon. These three new types of electric lamps were the Nernst, the Open Flame Arc and the Mercury Arc. The former is in the nature of an incandescent lamp, although radically different from any other lamps of that class, in that the filament, or "glower", as it is termed, made from some of the so-called rare earths (zirconia, yttria, etc.) is of the "solid-electrolyte" conductor type; that is, it is a non-conductor at ordinary temperatures and requires a heating coil to raise it at starting to the necessary temperature for it to become a conductor. Another peculiarity is that since the glower conducts by electrolysis, the presence of oxygen is required to prevent it from rapidly disintegrating. Thus it cannot operate without air, so that it is not sealed up in a bulb from which the air has been exhausted, as with other types of incandescent lamps. On alternating current, however, this effect is much less marked than on direct current. Also, unlike ordinary incandescent lamps, its volt-ampere characteristics over its most efficient operating temperature range are similar to those of an arc, and it is necessary to use a steadying resistance consisting of iron wire, sealed up in a glass tube filled with inert gas, to prevent deterioration, which introduces a loss of about 10% in operating Nernst lamps on constant potential. In Europe, the glower was made in spiral shape, mounted either horizontally or vertically, dependent upon the light distribution desired. In this country, the most common form was with glowers in the shape of short, round rods mounted side by side in a horizontal position. With this latter arrangement the greater part of the light is thrown in a downward direction. Therefore, comparison with the carbon incandescent lamp on a mean horizontal candle-power basis (carbon filament 3.1 w.p.m.hor.c.p. —American Nernst 3.75 w.p.m.hor.c.p.) is not as significant an

indication of their relative illuminating values as a consideration of the mean lower hemispherical candle-power figures (carbon filament lamp equipped with reflector 3.0 w.p.m.l.h.c.p. —American Nernst 2.17 w.p.m.l.h.c.p.).

This type of illuminant burns with a steady light rather whiter than the ordinary carbon incandescent lamp, and the "life" of the glowers was about 600 to 800 hours. It was perfected for use on 220-volt D. C. circuits and for any A. C. multiple or series circuit by means of suitable small individual transformers. The lamp was first made in several sizes, utilizing from one to six glowers in multiple, ranging from 88 to 528 watts. The minimum size of lamp was a one-glower unit rated at 50 c.p., but later a 25-c.p. 44-watt multiple size and a 115-watt series A. C. single-glower type were standardized. These lamps proved particularly effective in meeting "gas" competition and were produced in large quantities, starting about 1902. The A. C. style was used exclusively in this country at first; while abroad, where the lamp was much favored, the direct-current type was equally popular with the A. C. from the start. Upon the advent of the tungsten lamp, however, it was impossible for the Nernst lamp to compete.

Open Flame Arc Lamp.

The open-flame arc lamp was developed in Europe and consisted essentially of impregnating or coring one or both of the carbon electrodes of an open-arc lamp with highly efficient light-giving salts (fluorides of calcium, cerium, etc.), so that by being evaporated by the heat of the carbon arc they are fed into the arc stream and make it intensely luminous. In order to prevent excess particles of the flaming material, in the form of slag, from lodging between the electrodes in such a way as to insulate the carbon points from each other, at starting or when "feeding", many of the lamps are made with the electrodes inclined towards each other at an angle of about 30 deg., with the arc maintained between the lower points. A blow magnet is provided that forces the arc downwards into a fan shape. The "smoke" from arcs of this kind condenses as a white powder, so that effective means of ventilation must be provided to prevent the inside of the glass protecting globe from becoming heavily coated with such deposits. Lamps with vertical

co-axial electrodes were also developed by some manufacturers, the lower electrode being positive in most cases, as this arrangement seems to act better in preventing arc interruptions due to "slag" formations.

These open-flame arc lamps, which give a steady, reddish-yellow light of great intensity, gained much popularity abroad, particularly in Germany, where several in series were operated from D. C. constant-potential circuits. It is also made for A. C. connection, either in multiple or from auto-transformers. The arc voltage of this lamp is about 45 volts at 10 or 12 amperes, and the "life" per trim of electrodes is 12 or 18 hours, dependent upon the lengths used.

It was not until about 1906 that the open-arc flame lamps were marketed in America, being first utilized for spectacular lighting of all kinds, amusement parks, in front of theatres and stores, for bill-board lighting, etc. An increasing number were then imported and domestic types also produced for the lighting of large industrial plants, docks, railroad yards, buildings under construction, and even to a limited extent for street lighting. Due largely to the fact that these lamps required such frequent trimming, with very expensive carbons (largely imported), and to the further fact that the most attractive efficiency can only be secured with yellow light, as white light carbons are much less efficient, the sale for these short-life open-arc flame lamps gradually fell off in America as new types of long-life high candle-power units with better color values became available. They still remained popular abroad, with trimming labor and good electrodes so cheap.

Enclosed Flame Arc Lamp.

Many attempts were made, particularly in England, to produce long-burning flame arc lamps. Several types involving multiple-carbon and magazine feed, but operating on the open-arc principle, were tried out commercially with slight success, due to the complication of mechanism and the tendency of the moving parts to clog up and stick from the effects of the fumes and deposits from the impregnated electrodes. The first long-burning lamp that was at all successful was invented in England about 1907 and worked on the enclosed-arc principle, with special arrangements of vertical cooling tubes for condensing

the fumes so as to prevent the deposits from them from forming on the inner surface of the enclosing globe. A more attractive lamp, also of the enclosed-arc type but with a condensing chamber above the arc in a position where it could not obstruct the useful light, was invented in Germany about 1909.

Both of these lamps were later imported to this country, and several domestic designs similar to the latter type were also marketed, beginning in 1910. They are made suitable for service on all kinds of D. C. and A. C. commercial circuits, except A. C. circuits of less than 40 cycles. The D. C. multiple lamps are wound for 6 to 6½ amperes and adjusted for 65 to 75 volts at the arc, and the A. C. lamps, through self-contained auto-transformers, take from 6 to 7½ amperes from the line, stepped-up to 10 amperes through the arc, with 50 to 55 volts at arc. Carbons are of the homogeneous type, of large diameter (about ⅞ in.) and are obtainable for either yellow or white light, the yellow being much more efficient than the white. The electrodes are vertical and co-axial and give from 100 to 140 hours per trim.

These lamps have been used in considerable quantities for the same class of lighting as was served by the short-life flame-arc lamps (in fact replacing the older type in many cases, as the cost of maintenance is less than one-quarter as much), and to quite an extent, generally equipped with white-light carbons, for street lighting. Since they can replace series A. C. enclosed-carbon arcs without change of circuit wiring or of the regulating apparatus in the station, they are quite attractive for such installations. The limitation of this type of illuminant is that the best results as to steadiness and illuminating qualities can only be obtained with yellow light, which is not popular in this country except for limited classes of application. The introduction of an inexpensive white-light electrode of high efficiency and good steadiness would do much to increase the interest in this lamp.

Mercury Vapor Lamp.

The Cooper-Hewitt low-pressure type of Mercury Vapor arc lamp, looking very unlike the conventional arc lamp, although by its characteristics it essentially is a true arc, was first exploited about 1902. It consists of a glass tube one inch

in diameter, about 2 or 4 feet long according to the supply voltage, enlarged at one end to hold mercury, which constitutes the cathode material, and at the other to form a condensing chamber for the mercury vapor. Contact is made through the glass to the mercury to form the negative terminal; an electrode of iron, or of most any other conducting material, at the other end of the tube forms the anode, and the tube is exhausted so that it contains nothing except mercury. Like other arcs, it is necessary to use series resistance with it in order to make it stable on constant potential. The arc is started by tilting the tube from the inclined position in which it is designed to operate, so that the mercury momentarily short-circuits the space between the two electrodes. The arc fills the full length of the tube, due to being confined, and the light from it is very steady, quite brilliant, but has almost no red rays, being bluish-green in color. The feeding of the lamp results by the condensation of the mercury vapor and its return by gravity to the cathode pool. Long tubes are designed to run singly, or shorter ones two-in-series across 110 volts direct current, or either size tubes can be run several in series for higher voltages. For alternating currents, tubes can be operated on any desired voltage by means of auto-transformers. The depreciation in light amounts to about 20% in 2000 hours. These lamps all take about 400 watts and consume at best about 0.72 watts per mean spherical candlepower.

Due to the bad color value of this type of lamp, it has not been suitable for use except where color considerations are of secondary importance. On the other hand, for photographic work it is peculiarly well adapted, can be utilized strikingly for advertising purposes and is very successfully used in certain industrial processes for the detection of flaws and imperfections of surface and structure. Various attempts have been made to correct its color deficiency, but none of them have proven efficient enough to be attractive.

Due to the remarkable efficiency of this type of lamp and its long life, it has had extensive use, particularly in printing establishments and other industrial plants. Other types of low-pressure mercury-vapor lamps have been brought out abroad, but have not been imported to America. One type in particu-

lar that has been popular in England has a much shorter arc than that of the Cooper-Hewitt lamp and the whole unit has the appearance of an arc lamp. The "ballast" resistance in this lamp is in the form of an "under-run" incandescent filament, the red and yellow rays from which tend to correct the light from the mercury arc.

Quartz Tube.

Another form of mercury-vapor lamp, known both as the Quartz Tube and as the High-Pressure Mercury Arc, was first developed in Germany about 1908, and by 1910 lamps of this kind were being used commercially in France and Germany. This lamp is identical with the glass (low-pressure) mercury arc, except that by the use of quartz instead of glass for the enclosing envelope it is possible to run the arc at much higher current density and greatly increased efficiency. Due to the higher temperature thus produced and the consequent higher vapor pressure, the arc length is reduced to only a few inches and the tube and controlling mechanism readily fit into a casing rather larger, but of the same general form, as an arc lamp housing. The specific consumption of this type of lamp, including losses in ballast resistance, is about 0.59 watt per mean spherical candle-power. It takes about 3.5 amperes and operates best on 220 volts D. C., although it is also made for 110 volts D. C. The life of a tube is from 3000 to 5000 hours. It has never been produced commercially for alternating current connection.

The light from the quartz tube has more red rays and is, therefore, superior to that from the glass mercury arc, due, it is thought, to the fact that the high temperature of the arc stream produces some light by pure temperature radiation or incandescence, but its color is still so green as to make it unsuited for purposes of general illumination. There are, however, useful applications for this lamp other than for lighting, since its arc is very rich in ultra-violet radiations; so rich in fact that it is essential to keep it covered by a glass globe to prevent serious injury to the eyes. As an ultra-violet light producer, therefore, this lamp is finding a variety of industrial applications—such as water sterilization, patent-leather drying, deblooming of oil, bleaching of flour, etc. On the other hand,

if any of the many attempts to efficiently correct its color value ever prove successful, it will immediately become a most attractive illuminant, with its marked efficiency and long life.

Moore Vacuum Tube.

About 1905, after more than ten years of experimental development, during which time various more or less elaborate demonstrations had been made at electrical shows, etc., several practical installations of Moore vacuum tubes were made around New York, operating from regular 60-cycle A. C. service mains. These tubes work on the familiar Geissler tube principle of light production by causing gases at low pressure to become luminous by the passage of current through them. The Moore vacuum tube consists of a continuous glass tube about 1¾ in. in diameter and from a few feet to several hundred feet in length, with internal electrodes of considerable size sealed into each end. The tube contains gas or vapor at low pressure and the color and efficiency of the light produced are dependent upon the character of the gas used. Rarified air gives a yellowish light with a slight rose tint, while pure nitrogen, which gave the most efficient results at that time, produces light of similar quality, as the predominant color in both cases is that of the spectrum of luminous nitrogen. Carbon dioxide gas used in the tubes emits light that is remarkably close in color to that of well diffused daylight, but unfortunately very much less efficiently (6.32 watts per mean spherical c. p.) than with the other gases. The extremely low intrinsic brilliancy of these tube sources of light makes the illumination from them appear very soft and uniform, although not so perfectly diffused as to appear flat. The specific consumption of the best operating nitrogen tubes is about 2.05 watts per mean spherical candle-power.

Due to the fact that the gases in the tube seem to gradually disappear, either by being driven into or combining with the glass or electrodes, the Moore tube is provided with an ingenious carbon plug valve by means of which gas is automatically fed into the tubes, so as to keep the enclosed gas constantly at the proper pressure. Simple auxiliary chemical devices are provided for generating, as required, the particular gas that is being used. By these means the tubes will run for several thousand

hours without appreciable reduction in candle-power. The tube is operated from a constant-potential transformer supplied from 60-cycle low-voltage service lines, with its secondary terminals connected directly to the electrodes in the ends of the tube. Several thousand volts are required, dependent upon the length of the tube, but the transformer and ends of the tube are so encased and insulated as to leave no "live" parts exposed. Fully 30% of this voltage is taken up by the "drop" at the electrodes, and the reduction of this large loss is the great difficulty to be overcome to make this form of light production more efficient. The power factor of this outfit is about 56%, due to the fact that the internal reactance of the transformer has to be made high in order to overcome the unstable volt-ampere characteristics of the tubes on constant potential.

On account of the comparatively low efficiency of this form of lighting, particularly in producing white light, it has never made much progress commercially, except for spectacular advertising purposes, for photographic work, as the white tubes give highly actinic radiation, and for color matching. For this last application an attractive and convenient 500-watt portable outfit was developed.

Direct Current Series Luminous Arc Lamp.

In the fall of 1903, the first commercial demonstration and service test of the D. C. Series Luminous (Magnetite) arc lamp was started. This form of lamp was initially designed to operate from 4-ampere constant-current series arc machines, and is of the open-arc type; that is, it does not have an enclosing globe around the arc to restrict the access of air.

The upper and positive electrode is of heavy copper and lasts several thousand hours, and the lower and negative consists of a tube of iron filled with a mixture containing essentially the oxides of iron and titanium. The "life" of the standard lower electrode is about 175 hours. The arc stream is fed by the materials of this cathode; and the beautiful characteristic white light given by this type of arc, which is about ¾ in. long, running at 4 amperes and 80 volts, is largely due to the high luminous efficiency of the titanium salts.

The lamp mechanism is simple and rugged, working on the "drop and lift" principle, whereby the electrodes, being nor-

mally apart, are brought together momentarily at starting to "strike" the arc, immediately dropping apart again to the adjusted "fixed-arc gap". Feeding is accomplished by bringing the electrodes together again and re-establishing the proper arc length each time the arc voltage, due to electrode consumption, rises to a pre-determined value. In a long-burning lamp such as this one, the feeding operation occurs infrequently. This method of arc control was adopted, instead of the differentially-regulated "floating" mechanism commonly used in carbon-arc lamps, on account of the marked difference between the light emitting characteristics of carbon arcs and luminous arcs. In the former, since the arc stream gives scarcely any light, the arc length is not of first importance; whereas, the light from the carbon points, which it is desired to maintain uniform, depends upon the current, and the floating control tends to keep the current steady by constantly changing the length of arc so as to counteract variations in arc resistance. In the case of the luminous lamp where the arc stream furnishes all the light, it is not only important to maintain the current constant, but the arc length as well, since variations in either will cause unsteadiness of the light flux. This is best accomplished by fixed arc length, since floating regulation working for constant current would tend to shorten the arc when it was long and least luminous, thus making light fluctuations more pronounced. With fixed arc length and constant current, the arc voltage varies over a wide range, but with many lamps in series the average per lamp is satisfactory.

These considerations are of further interest on account of their bearing on the designing of luminous lamps for multiple and series-multiple connection on constant potential, which has never been successfully accomplished due to inherent unsteadiness, as above indicated. It would seem to be no more difficult to make a multiple luminous lamp than a multiple flame, as they both emit their light from the arc stream, and the reason seems to be that higher currents are used for flame lamps, and carbon is used in the electrodes, both of which expedients greatly tend to stabilize the arc by furnishing a large volume of good conducting vapor.

The 4-ampere series luminous-arc lamp, taking about 310

watts, was able to displace open and enclosed carbon lamps of 480 watts, not alone because of its high efficiency (about 1 w. per mean spherical c. p.), its white light and low maintenance cost, but due also to the fact that its light distribution is a maximum at 10° below the horizontal—making it ideal for street lighting. Therefore, its advent marked the beginning of the decline of the pure carbon arc for series lighting.

Mercury Arc Rectifier System.

The one disadvantage of the luminous system, as first exploited, compared with the method of operating series A. C. enclosed-carbon arc was the necessity of using many separately driven-series D. C. arc machines instead of being able to connect a number of circuits to large constant-potential transformers through constant-current transformers or regulators. In 1906 this objection was overcome by the introduction of the mercury-arc rectifier, by means of which direct current is produced from an A. C. system similar to that used for series A. C. arc circuits by simply rectifying the current on the lamp side of the constant-current transformers. About 1909, due to an evident demand for a higher standard of illumination in American cities, a 6.6-ampere luminous lamp (0.65 per mean spherical c. p.) was put on the market, the 4-ampere rating being retained as well. The "life" per trim of the former is from 100 to 125 hours.

This luminous arc system proved attractive to operating companies, not only on account of its superior illuminating qualities, as compared with previous methods, but especially due to its reliability, improved efficiency and low maintenance cost, and many thousands of these lamps have been installed.

Direct Current Intensified Enclosed Arc.

Starting about 1907, and for several years after, due apparently to the development and exploitation of the metallized carbon and metal filament incandescent lamps encroaching upon the field of the older types of multiple enclosed-type arc lamps, many attempts were made to gain greater steadiness, superior quality of light and better efficiency with carbon arcs by increasing the current density at the points of the electrodes. This could only be accomplished by using carbons of extremely small diameter, since it was also essential to keep the units as low in current consumption as possible. Furthermore, in order to

economize electrode life and avoid the complication of running such lamps in multiple-series on constant potential, the lamps had to be preferably of the enclosed, or at least semi-enclosed, type. Many small arc lamps of almost miniature size were built here and abroad, some of the European models taking carbons as small as 1/8 in. diameter and capable of running only a few hours per trim. Others used carbons, some of pure carbon and some cored with more efficient light-giving salts, 3/16 in. and 1/4 in. diameter, with electrode lives of from 10 to 40 hours. Many of them gave a beautifully white, steady light; but due to the fact that they had to be trimmed so often and with such care, on account of the trouble of aligning long thin carbons, and the further fact that many of them were so small as to present insufficient radiating surface to properly dissipate the heat from the ballast resistance and the arc so that they ultimately destroyed themselves, this form of illuminant did not gain permanent favor.

The D. C. Intensified Enclosed-Arc Lamp, however, a lamp of full size and of extremely ornate appearance, successfully entered this field in 1909. It produced a steady white light of high efficiency, and by means of a novel arrangement of carbons, gave a life of about 60 hours. Two inclined carbons, 1/4 in. in diameter, brought into abutment at their lower tips formed the upper positive electrode; and a single vertical carbon, 3/8 in. diameter, actuated by the lamp mechanism was the negative electrode, and by its movement regulated the arc. This lamp had a specific consumption of about 1.76 watts per mean spherical candle-power. It proved quite popular for use in department stores and other places where a steady white light was required.

Osmium Incandescent Lamp.

In the year 1904, the twenty-fifth anniversary of the invention of the incandescent lamp, Mr. Edison stated that up to that time a total of about 250,000,000 incandescent lamps had been produced in America. All these lamps had filaments of carbon and the efficiency had been brought some years before to the point where a standard 16-c.p. lamp had, with satisfactory useful life, a specific consumption of 3.1 watts per mean horizontal candle-power; and other ratings, 3.5 and 4 w.p.m.hor.c.p. It seemed as if the limit of efficiency had been reached with the carbon filament; and with no improvements in sight, except the

Osmium lamp under development in Germany, and with the Nernst lamp (smallest size, 25 c. p.) making good headway for both indoor and outdoor illumination, the outlook for the incandescent lamp just at that time was not of the brightest. Incandescent lamps with osmium filaments were first tried out commercially in Berlin and Vienna in 1904. The lamps operated at about 1.5 w.p.m.hor.c.p. with good commercial life, but could only be made for low voltages of from 10 to 55 volts, and the filaments were very fragile. Due to the fact that the known supply of osmium was extremely small, the cost of the lamps was high, and many of them were rented rather than sold so as to recover the osmium after the failure of the lamp, as it could be used over again.

Tantalum Incandescent Lamp.

In 1905 the Tantalum lamp was brought out in Germany, and appeared in this country the next year, 1906. It had a strong filament that withstood shipment and vibration very well, gave 800 to 1000 hours' life on D. C. at 2 w.p.m.hor.c.p., but unfortunately gave less than half the life on A. C. that it did on D. C.

Metallized Carbon Incandescent Lamp.

Also in 1906 announcement was made in America of the discovery of the "metallized carbon" filament, rated at 2.5 w.p.m.hor.c.p. The process of making this filament consists of heating ordinary carbon filaments in a furnace at a temperature of over 3000° C., both before and after "treating" in hydrocarbon vapor. By this means the graphite coating of the filament is greatly reduced in resistance, and its temperature coefficient becomes positive instead of negative, as before. These changes in characteristics make it capable of withstanding higher temperature, so that it can be run at better efficiency and still give good life. This lamp, known on the market as the "Gem", immediately became a formidable competitor of the tantalum lamp because of its cost, which was only slightly above that of the ordinary carbon lamp, while the cost of the tantalum was three times as much, and also on account of the poor life of the latter on A. C. circuits. Still, with its very attractive efficiency, sturdiness and long life on D. C., many hundred thousands of tantalum lamps were sold.

"Pasted" Tungsten Incandescent Lamp.

In this same year of 1906 the "pasted" tungsten filament lamp was put out abroad, and in this country in 1907. Its specific consumption at satisfactory commercial life was announced to be 1.25 w.p.m.hor.c.p., which was such a wonderful improvement as to instantly attract wide attention. The early lamps were, however, so very fragile that it was difficult to even ship them with safety. This fact, together with their high cost, which was even more than that of tantalum lamps, somewhat restricted their use in the beginning.

High candle-power, thick-filament lamps were first made in this country, as they stood up better than the finer filament lamps and also advanced the sizes of incandescent lamps beyond where they had ever been with carbon filaments. At first it was thought that due to the fragility of the fine tungsten filaments required for low-wattage lamps at 110 volts, it would be necessary to make such sizes in low voltages and operate them on higher voltages by means of individual and group transformers, but in a year or so tungsten lamps for 110-volt service that would withstand reasonable handling were made in sizes from 25 to 250 candle-power, and their cost was consistently reduced as the production increased. It was desirable to burn these lamps in a vertical position and not to control them by means of the socket switch. In cases where they were subject to appreciable vibration, spring-supported sockets were used to advantage to prevent undue filament breakage.

At the end of the third decade of electric lighting, the luminous-arc system with mercury-arc rectifier was getting more and more popular for street illumination and larger units than ever before were coming into use for series incandescent lighting. The Nernst lamp had started on the wane, due to tungsten competition, as had also all the enclosed-carbon arcs, except the recently exploited high efficiency arcs. The tungsten lamp was commencing to out-distance the tantalum lamp, although the latter's ruggedness on D. C. was much in its favor. The metallized carbon filament was making steady progress due to its good efficiency, increasing reliability and low cost. The open-flame-arc lamp was about at the highest point of its popularity and there was a general feeling that a practical long-life flame

lamp should be forthcoming, as the frequent trimming of the short-life flame lamps made them extremely costly to maintain. The mercury arc in a quiet way seemed to be making favorable progress in its somewhat limited fields of usefulness.

It is again interesting to note the extent to which carbon was being used at that time in electric illuminants, and it appears that it was still indispensably useful in the many "treated" and "metallized" filaments that were being manufactured for the electrodes of open and enclosed arc lamps and as the base for flame carbons, but it had lost the pre-eminent position it occupied during the first twenty years of the electrical industry.

Ornamental Fixtures.

About the year 1910 there seemed to be a more or less consistent inclination throughout this country in the direction of better lighting and more ornamental fixtures. This feeling was probably engendered by the great strides that were being made about that time in the perfecting of new illuminants, each successively better than its predecessor, and the fact that incandescent lamps advanced by their wonderful improvement in efficiency into a broader field, and being more susceptible of ornamentation than the old types of arc lamps, influenced the introduction of new fixtures more pleasing and ornate.

Ornamental Luminous Arc Lamp.

In the five years since 1910, tungsten cluster pole lighting first gained considerable popularity and then declined, due to the fact that it proved disappointing from an illuminating standpoint. Tungsten lamps in larger sizes than ever before and in increasing quantity were used for series and multiple street lighting. The ornamental luminous arc for pole lighting was brought out in 1910 and has met with permanent and increasing success in the lighting of the business streets, parkways, and boulevards of cities, large and small. It is made in three ratings, namely, 4, 5 and 6.6 amperes, and is operated from standard series rectifier outfits. The beautiful white light given by these lamps has given rise to the term "White Way" lighting. The white light from such street lamps makes a pleasing contrast with the yellow light in store windows, hotels and residences.

COMPARATIVE DATA ON SERIES ARC LAMPS.

	1. 9.6 AMP. D.C. OPEN ARC. 7/16" SOLID CARBONS CLEAR GLOBE	2. 6.6 AMP D.C. ENCLOSED ARC. 1/2" SOLID CARBONS OPAL INNER GLOBE CLEAR OUTER GLOBE. STD. STREET REFLECTOR	3. 6.6 AMP A.C. ENCLOSED ARC. 1/2" CARBONS, UPPER CORED, LOWER SOLID. OPAL INNER GLOBE, CLEAR OUTER GLOBE. STD. ST. REFL.	4. 7.5 AMP A.C. ENCLOSED ARC. 1/2" CARBONS, UPPER CORED, LOWER SOLID. OPAL INNER GLOBE, CLEAR OUTER GLOBE. STD. ST. REFL.	5. 4 AMP D.C. LUMINOUS ARC. 5/8"X8" MAGNETITE LONG LIFE ELECTRODE. CLEAR GLOBE, INTERNAL CONCENTRIC REFLECTOR	6. 4 AMP D.C. LUMINOUS ARC 11/16"X8" MAGNETITE HIGH EFFICIENCY ELECTRODE. CLEAR GLOBE, INTERNAL CONCENTRIC REFLECTOR.	7. 4 AMP D.C. LUMINOUS ARC. 11/16"X9 1/2" MAGNETITE LONG LIFE ELECTRODE. CLEAR GLOBE, INTERNAL CONCENTRIC REFLECTOR
ELECTRICAL DATA.	1	2	3	4	5	6	7
AMPERES AT TERMINALS	9.6	6.6	6.6	7.5	4	4	4
VOLTS AT TERMINALS	50	75-80	77	76	75-80	75-80	75-80
WATTS AT TERMINALS	480	510	425	480	310	310	310
LINE LOSS %	5	5	5	5	2	2	2
REGULATOR EFFICIENCY %	82	82	96	96	92	92	92
COMBINED EFFICIENCY %	78	78	91.5	91.5	90.2	90.2	90.2
WATTS AT SWITCHBOARD	616	655	465	525	344	344	344
KILOWATT HRS. PER YEAR OF 4000 HRS.	2464	2620	1860	2100	1376	1376	1376
LIFE PER TRIM, HRS. (RATED)	12	130	150	100	188	125	350
NO. OF TRIMS PER YEAR OF 4000 HRS.	334	31	27	40	21	32	12
POWER FACTOR OF SYSTEM %	—	—	78.5	—	64	64	64
ILLUMINATION DATA							
MEAN LOWER HEMISPHERICAL C.P.	736	520	232	291	460	682	426
C.P. AT 10° BELOW HORIZONTAL	480	480	245	300	540	835	583
MAX. C.P. & DEGREES BELOW HOR.	1220-42°	610-38°	255-25°	315-25°	550-5°	835-10°	583-10°
TOTAL LUMENS	5650	780	1810	2170	3200	4785	2850
TOTAL LUMENS PER WATT	11.8	7.42	4.25	4.5	10.3	15.4	9.2
HOR. F.C. 150 FT. FROM LAMP 25 FT. HIGH	.0033	.0034	.0017	.0022	.0038	.0059	.0041
HOR. F.C. 50 FT. FROM LAMP 15 FT. HIGH.	—	—	—	—	—	—	—

	8. 4 AMP D.C. LUMINOUS ARC 11/16"X9 1/2" MAGNETITE HIGH EFFICIENCY ELECTRODE. CLEAR GLOBE, INTERNAL CONCENTRIC REFLECTOR.	9. 4 AMP D.C. LUMINOUS ARC 11/16"X9 1/2" MAGNETITE HIGH EFFICIENCY ELECTRODE. CLEAR GLOBE PRISMATIC GLASS REFRACTOR	10. 5 AMP D.C. LUMINOUS ARC 11/16"X9 1/2" MAGNETITE LONG LIFE ELECTRODE. CLEAR GLOBE, INTERNAL CONCENTRIC REFLECTOR.	11. 5 AMP D.C. LUMINOUS ARC. 11/16"X9 1/2" MAGNETITE HIGH EFFICIENCY ELECTRODE. CLEAR GLOBE, INTERNAL CONCENTRIC REFLECTOR	12. 5 AMP D.C. LUMINOUS ARC. 11/16"X9 1/2" MAGNETITE HIGH EFFICIENCY ELECTRODE. CLEAR GLOBE, PRISMATIC GLASS REFRACTOR.	13. 6.6 AMP D.C. LUMINOUS ARC. 11/16"X9 1/2" MAGNETITE LONG LIFE ELECTRODE. CLEAR GLOBE, INTERNAL CONCENTRIC REFLECTOR.
ELECTRICAL DATA.	8	9	10	11	12	13
AMPERES AT TERMINALS	4	4	5	5	5	6.6
VOLTS AT TERMINALS	75-80	75-80	75-80	75-80	75-80	75-80
WATTS AT TERMINALS	310	310	388	388	388	510
LINE LOSS %	2	2	3	3	3	5
REGULATOR EFFICIENCY %	92	92	92	92	92	92
COMBINED EFFICIENCY %	90.2	90.2	89.5	89.5	89.5	87.6
WATTS AT SWITCHBOARD	344	344	434	434	434	582
KILOWATT HRS. PER YEAR OF 4000 HRS.	1376	1376	1736	1736	1736	2328
LIFE PER TRIM, HRS. (RATED)	155	150	225	120	120	125
NO. OF TRIMS PER YEAR OF 4000 HRS.	26	27	18	33	33	32
POWER FACTOR OF SYSTEM %	64	64	63	64	64	64
ILLUMINATION DATA						
MEAN LOWER HEMISPHERICAL C.P.	645	698	706	1031	1017	1195
C.P. AT 10° BELOW HORIZONTAL	840	1630	870	1360	2120	1510
MAX. C.P. & DEGREES BELOW HOR.	855-13°	1630-10°	900-20°	1360-10°	2120-10°	1530-15°
TOTAL LUMENS	4350	5030	4720	6960	7260	8110
TOTAL LUMENS PER WATT	14.0	16.2	12.2	18.0	18.7	15.9
HOR. F.C. 150 FT. FROM LAMP 25 FT. HIGH	.006	.0116	.0061	.0096	.015	.0106
HOR. F.C. 50 FT. FROM LAMP 15 FT. HIGH.	—	—	—	—	—	—

	14. 4 AMP D.C. ORNAMENTAL LUMINOUS ARC. 9/16"X18" MAGNETITE HIGH EFFICIENCY ELECTRODE. ALBA GLOBE.	15. 5 AMP D.C. ORNAMENTAL LUMINOUS ARC. 9/16"X18" MAGNETITE HIGH EFFICIENCY ELECTRODE. ALABASTER GLOBE.	16. 5 AMP D.C. ORNAMENTAL LUMINOUS ARC. 9/16"X18" MAGNETITE LONG LIFE ELECTRODE, ALBA GLOBE.	17. 6.6 AMP D.C. ORNAMENTAL LUMINOUS ARC. 9/16"X15" MAGNETITE LONG LIFE ELECTRODE. ALABASTER GLOBE.	18. 10 AMP A.C. FLAME ARC. 7/8"X14" WHITE CARBONS. CLEAR INNER GLOBE, ALBA OUTER GLOBE	19. 10 AMP A.C. FLAME ARC. 7/8"X14 YELLOW CARBONS. CLEAR INNER GLOBE, ALBA OUTER GLOBE
ELECTRICAL DATA.	14	15	16	17	18	19
AMPERES AT TERMINALS	4	5	5	6.6	10	10
VOLTS AT TERMINALS	80-85	78-83	78-83	78-83	57-63	57-63
WATTS AT TERMINALS	330	403	403	532	465	465
LINE LOSS %	2	3	3	5	5	5
REGULATOR EFFICIENCY %	92	92	92	92	96	96
COMBINED EFFICIENCY %	90.2	89.5	89.5	87.6	91.5	91.5
WATTS AT SWITCHBOARD	366	456	456	607	508	508
KILOWATT HRS. PER YEAR OF 4000 HRS.	1464	1824	1824	2428	2032	2032
LIFE PER TRIM, HRS. (RATED)	180	138	238	113	130	130
NO. OF TRIMS PER YEAR OF 4000 HRS.	22	29	17	36	31	31
POWER FACTOR OF SYSTEM %	64	64	64	64	64	64
ILLUMINATION DATA						
MEAN LOWER HEMISPHERICAL C.P.	434	657	429	784	1090	1244
C.P. AT 10° BELOW HORIZONTAL	560	765	530	933	1235	1400
MAX. C.P. & DEGREES BELOW HOR.	565-7°	780-20°	530-10°	933-10°	1235-10°	1400-10°
TOTAL LUMENS	4970	7470	5020	9120	9940	11320
TOTAL LUMENS PER WATT	15.1	18.5	12.5	17.1	21.4	24.3
HOR. F.C. 150 FT. FROM LAMP 25 FT. HIGH	—	—	—	—	.0088	.010
HOR. F.C. 50 FT. FROM LAMP 15 FT. HIGH.	.055	.080	.056	.097	—	—

COMPARATIVE DATA ON MULTIPLE LAMPS.

	D.C. MULTIPLE EN-CLOSED ARC. ½" SOLID CARBONS OPAL INNER GLOBE CLEAR OUTER GLOBE STREET REFLECTOR		A.C. MULTIPLE EN-CLOSED ARC. ½" CARBONS, ONE CORED, ONE SOLID. OPAL INNER GLOBE CLEAR OUTER GLOBE STREET REFLECTOR		D.C. MULT. ENCLOSED FLAME ARC. YELLOW CARBONS, CLEAR INNER GLOBE, DIFFUSING OUTER GLOBE.	D.C. MULT. ENCLOSED FLAME ARC. WHITE CARBONS, CLEAR INNER GLOBE, DIFFUSING OUTER GLOBE.	A.C. MULT. ENCLOSED FLAME ARC, AUTO TRANS. YELLOW CARBONS, CLEAR INNER GLOBE, DIFFUSING OUTER GLOBE.	A.C. MULT. ENCLOSED FLAME ARC. AUTO TRANS. WHITE CARBONS. CLEAR INNER GLOBE, DIFFUSING OUTER GLOBE.	D.C. MULT. MERCURY ARC. GLASS TUBE METAL TROUGH REFLECTOR.	D.C. MULT. MERCURY ARC. QUARTZ TUBE. DIFFUSING GLOBE METAL TROUGH REFLECTOR		A.C. MULT. MERCURY ARC. GLASS TUBE. METAL TROUGH REFLECTOR.	GEM LAMP METALIZED FILLAMENT PRISMATIC GLASS REFLECTOR	TUNGSTEN LAMP VACUUM. PRISMATIC GLASS REFLECTOR	TUNGSTEN LAMPS GAS FILLED METAL REFLECTOR BOWL TYPE		
ELECTRICAL DATA.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
AMPERES AT TERMINALS	5	6	6	7.5	6.5	6.5	7.5-10	7.5-10	3.3	4	3.5	7	2.2	5.45	4.35	6.52	8.7
VOLTS AT TERMINALS	110	110	104	104	110	110	110	110	110	110	220	110	110	110	115	115	115
WATTS AT TERMINALS	550	660	430	540	715	715	540	540	363	440	770	425	50	60	500	750	1000
ILLUMINATION DATA.																	
MEAN HEMISPHERICAL C.P.	342	451	227	307	1807	1205	1244	1120	567	557	1956	888	21	63.9	900	1458	2070
MAX. C.P. & DEGREES	370-60°	440-60°	237-65°	320-65°	3000-58°	2000-58°	1400-70°	1260-70°	970-0°	1000-10°	3100-30°	1340-0°	32-40°	82-40°	1480-35°	2400-35°	3800-35°
TOTAL LUMENS	2440	3210	1680	2270	15490	10320	11180	10400	3620	4000	14300	5950	186	529	5025	8120	13030
TOTAL LUMENS PER WATT	4.4	4.9	3.9	4.2	21.7	14.5	20.7	19.3	10.0	9.1	18.6	14.0	3.7	8.8	10.1	10.8	13.0
LIFE, HOURS. (RATED)	140	130	115	100	120	120	120	120	—	—	—	—	700	1000	1000	1000	1000
KILOWATT HRS. PER YEAR OF 1000 HRS.	550	660	430	540	715	715	540	540	363	440	770	425	50	60	500	750	1000
NO. OF TRIMS PER YEAR OF 1000 HRS.	7	8	9	10	8	8	8	8	—	—	—	—	1.4	1	1	1	1

COMPARATIVE DATA ON SERIES GAS FILLED TUNGSTEN LAMPS.

	400 C.P. TUNGSTEN PENDENT STREET LIGHTING UNIT. DIFFUSING GLOBE METAL REFLECTOR.	400 C.P. TUNGSTEN PENDENT STREET LIGHTING UNIT. PRISMATIC GLASS REFRACTOR METAL REFLECTOR.	600 C.P. TUNGSTEN PENDENT STREET LIGHTING UNIT. DIFFUSING GLOBE METAL REFLECTOR.	600 C.P. TUNGSTEN PENDENT STREET LIGHTING UNIT. PRISMATIC GLASS REFRACTOR METAL REFLECTOR.	1000 C.P. TUNGSTEN PENDENT STREET LIGHTING UNIT. DIFFUSING GLOBE METAL REFLECTOR.	1000 C.P. TUNGSTEN PENDENT STREET LIGHTING UNIT. PRISMATIC GLASS REFRACTOR METAL REFLECTOR.	600 C.P. TUNGSTEN ORNAMENTAL STREET LIGHTING UNIT. DIFFUSING GLOBE	1000 C.P. TUNGSTEN ORNAMENTAL STREET LIGHTING UNIT. DIFFUSING GLOBE	100 C.P. TUNGSTEN PENDENT STREET LIGHTING UNIT. RADIAL WAVE REFLECTOR.	600 C.P. TUNGSTEN PENDENT STREET LIGHTING UNIT. DIFFUSING GLOBE METAL REFLECTOR
ELECTRICAL DATA.	1	2	3	4	5	6	7	8	9	10
AMPERES AT TERMINALS	6.6-15	6.6-15	6.6-20	6.6-20	6.6-20	66-20	6.6-20	6.6-20	6.6	6 6
VOLTS AT TERMINALS	36.5	36.5	50.2	50.2	82.7	82.7	50.2	82.7	10.8	58.2
WATTS AT TERMINALS	213	213	300	300	474	474	300	474	71.3	384
LINE LOSS %	5	5	5	5	5	5	5	5	5	5
REGULATOR EFFICIENCY %	96	96	96	96	96	96	96	96	96	96
COMBINED EFFICIENCY %	91.5	91.5	91.5	91.5	91.5	91.5	91.5	91.5	91.5	91.5
WATTS AT SWITCHBOARD	235	235	328	328	518	518	328	518	77.9	420
KILOWATT HRS. PER YEAR OF 4000 HRS.	940	940	1312	1312	2072	2072	1312	2072	312	1680
LIFE PER TRIM, HRS. (RATED)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
NO. OF TRIMS PER YEAR OF 4000 HRS.	4	4	4	4	4	4	4	4	4	4
POWER FACTOR OF SYSTEM %	91.7	91.7	91.7	91.7	91.7	91.7	91.7	91.7	91.7	91.7
ILLUMINATION DATA.										
MEAN LOWER HEMISPHERICAL C.P.	351	333	526	487	877	819	330	535	133	526
C.P. AT 10° BELOW HORIZONTAL	310	790	465	1140	775	1865	366	610	142	465
MAX. C.P. & DEGREES BELOW HOR.	390-60°	790-10°	590-60°	1140-10°	975-60°	1865-10°	366-10°	620-15°	142-10°	590-60°
TOTAL LUMENS	2650	2400	3970	3560	6630	3930	3855	6230	902	3970
TOTAL LUMENS PER WATT	12.4	11.3	13.2	11.9	14.0	12.5	12.92	13.1	12.7	10.3
HOR. F.C. 150 FT. FROM LAMP 25 FT. HIGH	.0022	.0056	.0033	.0081	.0055	.0132	—	—	—	.0033
HOR. F.C. 50 FT. FROM LAMP 15 FT. HIGH.	—	—	—	—	—	—	.040	.065	.015	—

Neon Vacuum Tube.

In 1911, exhibitions were made in America of the Claude Neon Tube invented in France. This is a tube similar to the Moore tube, except that it is supplied with pure neon gas instead of nitrogen or carbon dioxide. A peculiarity of this type of tube is that it does not need a valve arrangement for supplying additional gas, as with the Moore tube. Even a slight percentage of nitrogen impurity with the neon greatly reduces the efficiency. The light from this tube is rich in red rays, with entire absence of blue and violet, and when operated with mercury arc lamps the resultant quality of light is nearly white. A tube 20 ft. long takes 1000 volts to operate it.

Drawn-Wire Tungsten Incandescent Lamp.

In 1911 the first drawn-wire tungsten lamps of 1 w.p.m.hor. c.p. specific consumption were put out, looking more like tantalum lamps than like "pasted" filament tungsten lamps. Tungsten units of 400 and 500 watts were introduced and largely used for replacing multiple arc lamps in department stores, industrial plants, etc., as the efficiency of these new lamps was superior to that of most multiple arc lamps, and the inconvenience, dirt and expense of trimming is eliminated.

Gas-Filled Tungsten Incandescent Lamp.

In 1913 the remarkable innovation of making tungsten filaments in tightly wound spiral coil form and enclosing them in an atmosphere of nitrogen or other suitable gas was introduced. The gain in efficiency from this procedure is more pronounced with large diameter filaments than with thin ones, as the loss of heat by convection is relatively less with the thick filaments than with the smaller ones. For this reason, lamps of a specific consumption of 0.45 to 0.5 w.p.m.hor.c.p. are now being produced, with large filaments taking 20 amperes in 300-, 600- and 1000-watt sizes, and lamps taking 6.6 and 7.5 amperes at 0.6 to 0.7 w.p.m.hor.c.p., all for series connection. The 20-ampere lamps are operated by means of auto-transformers, which lower the efficiency of the 1000-watt combined unit to about 0.47 w.p. m.hor.c.p., and the others accordingly. Lamps for multiple 110 volts are made in 500-, 750- and 1000-watt sizes, taking from 0.6 to 0.8 w.p.m.hor.c.p. These lamps, particularly the high-current type, give a fine quality of light that appears white un-

less compared with a source like the luminous arc or Moore white-light tube, when it looks slightly yellowish. Step by step with these wonderful developments in incandescent lamps, improvements have been made in arc lamps, especially with the series luminous. By means of new materials and mixtures, so-called "high-efficiency" electrodes have been produced that have greatly increased the light production of these units. Rearrangement of lamp designs so as to lessen the amount of light lost by obstructions, and the use of prismatic refractors for gaining better distribution, have resulted in the salvage of much light heretofore absolutely lost.

At the present time, therefore, the illuminants that are most successful are the gas-filled incandescent and the luminous arc. For interior lighting, the incandescent lamp is practically supreme; while for street illumination, arc and incandescent lamps each have their most suitable applications, the former for the business sections of cities and towns, where white light is most dignified and effective, and for boulevards and parks, due to superior light distribution, and the latter for residential streets and suburban districts where a variety of sizes of units is desirable and the color of light is not contrasted with store-window lighting. From an installation and operative standpoint, the incandescent lamp system has lower first cost, since it requires no rectifying apparatus, but this advantage is rather more than offset by the better efficiency and lower maintenance cost of the luminous arcs.

It is interesting to note that electric lighting started with an open arc lamp and an incandescent lamp, both using incandescent carbon as the light source. We have arrived after many wanderings where we are again largely served by the same two types of lamps, with the difference that one uses metal oxides and the other, metal, as the light producers. Another point of similarity is that these arc lamps will only run on direct current, although efforts have long been made, with appreciable success, to perfect a similar type for alternating current.

It is both dangerous and futile to try to look into the future, but results already accomplished and work now progressing serve to indicate what paths new developments may quite possibly follow. For example, the flame lamp has latent possibilities

that may well put it far ahead of all other large sources, if new materials suitable for introduction into the electric arc can be found capable of producing steady light (preferably white light) more efficiently and economically than by present methods. It does not seem impossible that such discoveries may be made. On the other hand it really seems that the incandescent lamp has about reached the limit of its possible efficiency, as at the melting point of tungsten its specific consumption is about 0.2 watt per mean spherical candle-power. It has surprised us so often in the past, however, that it is not safe to discard it from consideration, as some day carbon may be converted into still another form that will enable it to be used at higher temperatures than tungsten. Possibly the small glass-bulb unit of the future will have a vapor path instead of a solid conductor, now that we are getting near the melting points of available filament materials. The real attractive and promising field for improvements seems to be in the utilization of luminous gases and vapors. Considerable progress has already been made and it seems not unreasonable that further successful developments will follow. There does not appear to be such hard and fast limitations to light production by gaseous conductors as by our old familiar methods, although this feeling may be due to the fact that we do not know so much about the laws governing such phenomena.

APPENDIX.

CLASSIFICATION OF ELECTRIC ILLUMINANTS.

All electrical illuminants may be classified broadly into two divisions:

First—Those in which the light-producing element is a "solid conductor".

Second—Those in which the light-producing element is, in part at least, a "gaseous conductor".

A more complete classification is as follows:

- Solid Conductor (Incandescent Lamps)
  - Glass Enclosed
    - Carbon Filament: Raw; Treated; Metallized
    - Tantalum Filament
    - Osmium Filament
    - Tungsten Filament: Vacuum; Gas-filled
  - Open-air Nernst Lamp
- Gaseous Conductor (Arcs and Vacuum Tubes)
  - Arcs
    - Carbon: Open; Enclosed
    - Flame: Open; Enclosed
    - Luminous: Magnetite; Titanium
    - Mercury: Glass envelope (low pressure); Quartz envelope (high pressure)
  - Vacuum Tubes: Moore Tubes; Claude Neon Tubes

Light Production.

Electric illuminants may also be grouped according to whether the light they produce is due entirely to "incandescence", or whether part of it is due to "luminescence", as follows:

- Incandescence
  - Pure Temperature Radiation
    - Carbon-filament incandescent lamps: Raw; Treated; Metallized
    - Carbon arcs: Open; Enclosed
  - Selective Radiation
    - Nernst Glower
    - Metal-filament incandescent lamps: Osmium; Tantalum; Tungsten
- Luminescence
  - Flame Arcs: Open; Enclosed
  - Luminous Arcs: Magnetite—D. C.; Titanium—A. C.
  - Mercury Arcs: Glass envelope (low pressure); Quartz envelope (high pressure)
  - Vacuum Tubes: Moore Tubes; Claude Neon Tube

Size of Unit and Divisibility.

Another important consideration regarding electrical illuminants is the size of units as to candle-power in which they are capable of being produced without appreciable sacrifice of efficiency. In general, the "solid conductor" lamps can be made in any desired size of units, whereas the "gaseous conductor" types can only be produced in minimum sizes of several hundred candle-power.

INCANDESCENT LAMPS.

Operation.

All incandescent lamps can be operated on either A. C. or D. C., and for both series and multiple connection. In certain cases the performance is superior on one or the other kind of current and practical considerations determine the most desirable connections.

Effect of Voltage Fluctuation.

The fact that all the new types of filaments have positive temperature coefficients is to give the lamps considerable inherent regulation. Tungsten lamps are, therefore, much less sensitive to change of line volts than old carbon-filament lamps were.

Effect of Frequency.

The variation of current through an incandescent-lamp filament caused by the periodic reversals of an alternating current produces like fluctuations in the light. At 60 cycles this continuous variation is hardly discernible, even with the smallest tungsten unit, and at 40 cycles it is not objectionable, but at 25 cycles it is quite perceptible. For equal candle-powers, the tungsten lamp is more susceptible to this effect than the old carbon lamp, due to its much thinner filament; but comparing filaments of the same actual diameter, tungsten is less affected.

Efficiency and Life.

Efficiency as a light producer and lamp "life" are interdependent and must necessarily be considered together. For, operating at low efficiency, a filament will last indefinitely, whereas the same filament run very brightly will last only a few hours or minutes. By convention, therefore, the efficiency of a

lamp is understood to be that at which it will operate for a certain number of hours (500 hours for carbon filaments and 1000 hours for metal) without falling below 80% of its initial candlepower. It has become customary to express this rating in specific consumption of watts per mean horizontal candlepower.

ARC LAMPS.

General Characteristics of Arcs.

Definition.—An arc is a bridge of conducting vapor maintained between electrodes included in an electric circuit.

Temperature.—The temperature of an arc is apparently that of the boiling point of the cathode material.

Influence of Cathode Material.—In fact, this material in general fixes the whole character of the arc providing the conducting vapor, and impressing its spectrum as that of the arc. The only way in which the anode material can affect the arc spectrum is when it is carried into the arc stream indirectly by evaporation. Under such circumstances, if the anode material is more volatile than that of the cathode and if the vapor from the latter is nearly non-luminous when used as an arc conductor, the spectrum of the arc may appear to be only that of the anode material.

Types of Arcs.

There are three distinct types of arcs, determined by the manner in which the light is produced, as follows:

1.—Light due to incandescence of the electrode tips, largely caused by the extremely high temperature of the anode crater.

So-called "carbon arcs" constitute this class, as pure carbon is used for both electrodes. Since carbon is the most refractory of known materials, it will maintain the highest producible temperature and give light at the best obtainable efficiency by incandescence. The diameter of the electrodes is quite an important factor with this type of lamp, as the smaller the diameter, at the same current, the better the efficiency and the steadiness; but these qualities can only be obtained at the expense of electrode "life". Since, however, the arc stream is formed from carbon vapor which is nearly non-luminous, over 90% of the light comes from the carbon tips.

2.—Light due to the arc stream being made luminous by

utilizing the heat of the anode crater to evaporate into it light-giving mineral salts that have been incorporated into the anode structure.

The so-called "flame arcs" that constitute this type always have carbon as the base of both electrodes due to the fact that it produces the hottest known arc, and thus the salts of high selective emissivity that are impregnated or cored into the anode, and sometimes into the cathode as well, are fed by evaporation into the hottest available arc, with resultant high efficiency. Various salts can be used for this purpose, but calcium in the form of fluoride, giving intensely yellow light, and cerium fluoride, producing white light but of less efficiency, are the most common ones utilized. Great care must be used with flame arcs to proportion the relative amounts of carbon and salts in the electrodes, so that at normal consumption uniform color and efficiency of the arc will be maintained. Nearly all the light from a flame arc is emitted by the arc stream and very little by the electrode tips, so that the type may be truly considered as a "colored" carbon arc.

3.—Light due to the arc stream being composed of the vapor from such cathode material that the passage of the arc current through it makes it luminous.

The so-called "luminous arcs" and also the "mercury arcs" come under this definition. The former utilize iron and titanium compounds as the material for the cathode, because they give the highest luminous efficiency and produce light very white in color. The oxides of these metals are used, as they are stable in the air, even at very high temperature, and thus make the electrodes have long life. With D. C. luminous arcs, the material of the anode, if it is kept comparatively cool, is not important, and may be practically non-consuming, since the light from this type of arc is largely due to "luminescence" and is not dependent upon very high temperature, as is light production by "incandescence". With A. C. luminous arcs, the anode must preferably be of carbon, as no other material is as effective as carbon in maintaining steady arcs with alternating current. The spectrum of the vapor of mercury, which material constitutes the cathode in the mercury-arc lamps, gives to these arcs their characteristic greenish-blue color.

Volt-Ampere Characteristics of Arcs.

A distinctive peculiarity of the arc is that at constant length the voltage decreases as the current increases, or, in other words, the resistance of the arc lowers with increase of current. This means that an arc is inherently unstable on constant potential, although stable with constant current.

A current-limiting or -steadying arrangement of some kind is, therefore, essential in circuit with an arc, to make it stable.

Arc on Constant Current.

For constant-current operation this stabilizing is accomplished by means of the generator, transformer or regulator that is designed to maintain constant current within required limits, irrespective of changes in load conditions.

Arc on Constant Potential.

For constant-potential operation the arc is made stable by using enough series resistance for direct current, or series reactance for alternating current, so that the total resistance or impedance of the arc plus its "ballast" will rise with increasing current, and vice versa.

Alternating Current Arc.

Due to the fact that with alternating current an arc at the end of each half cycle is extinguished, and if it is to be maintained must be each time re-established in the reverse direction, material of exceptional characteristics must be used for electrodes. It is necessary in order to start a new arc stream that the temperature of the arc be high enough so that the vapor of the particular material of which the electrodes are composed will remain volatile, and the arc gap, therefore, conductive, during the appreciable length of time while the current is reversing. As a matter of fact, carbon is the only known material that entirely fulfills this requirement at low voltages. At frequencies from 40 to 140 cycles, the light from an alternating current arc is satisfactory. Below 40 cycles the flicker due to the alternations begins to get noticeable, and with lower frequency becomes more and more objectionable. At the higher frequencies the arc develops a disagreeable humming noise. The arc current which determines the size of the unit, and also the quality of the carbons, influence these results.

Power Factor.

The power factor of an A. C. arc is also affected by the grade of carbons used, not due to actual phase shifting, but on account of the distortion of the voltage wave which at the beginning of each half cycle ''peeks up'' in order to overcome the resistance of the vapor gap in restarting the arc stream. With both carbons ''solid'', the distortion is most marked as the material is less volatile and there is a minimum of residual vapor, so that the restarting voltage rises to a high peek; with one ''solid'' and one ''cored'' carbon, the voltage at starting is much lower, while with two ''cored'' carbons there is very little distortion. With one cored and one solid carbon, which was the common practice in running enclosed-carbon arcs, the power factor of the arc averaged somewhat better than 90% at 60 cycles and would vary 5% either way with different combinations of electrodes.

Life.

The ''life'' of an arc lamp per trim of electrodes depends primarily upon the material of which the electrodes are composed, because with carbon, for example, more material is wasted by combustion than is volatilized to feed the arc stream. Thus the luminous-arc-lamp electrodes made of metallic oxides that are stable even at high temperatures are inherently long burning, whereas the only way to restrict the rapid consumption of carbon electrodes is to retard their combustion by limiting the amount of oxygen that reaches the arc.

The other points that affect ''life'' are, first, current, which influences the temperature and, therefore, the vaporizing power of the arc; and second, naturally, the size of the electrodes—that is, the amount of material available for consumption. With carbon, particularly, the diameter of the electrodes is of great importance, as long, slender sticks run hotter over a greater surface and thus oxidize faster than shorter, stubbier pieces of equal bulk.

Luminous arcs are, therefore, characteristically long burning; and carbon arcs, comprising also flame arcs, are of two kinds, namely, ''open arc'', or short life, and ''enclosed arc'' or ''long life''.

In mercury arcs, the cathode material does not consume, as

after it is vaporized into the arc stream it is condensed and returned to the cathode pool. The conventional limit of "life" of such lamps is considered to be when the light-producing power of the tube has been reduced 20% from the initial value, due to blackening caused by anode material depositing on or combining with the glass or quartz envelope.

CANDLE-POWER COMPARISONS.

Due to the ease of comparing the candle-power of incandescent lamps (especially bare lamps) with each other, it early became the custom to rate such lamps in mean horizontal candle-power. In the same way, arc lamps have often been rated in mean lower hemispherical candle-power, since they are ordinarily judged by their performance when fully equipped with globes, reflectors, refractors, etc., for actual service. The only fair way, however, of putting all light sources on a common footing is on the basis of total light flux emitted, expressed in mean spherical candle-power or lumens. Incandescent lamp manufacturers generally give with the standard horizontal candle-power rating of a lamp either a reduction factor that enables the mean spherical candle-power to be determined or the spherical rating itself in candle-power or lumens.

As mean spherical candle-power ratings do not indicate the characteristic distribution of light from different illuminants, it is often customary to furnish such information by stating the angle at which maximum candle-power is produced, and the candle-powers at such other angles as will be of interest in showing the suitability of the lamp for particular applications. The most satisfactory way of recording these data is by means of curves plotted on polar coordinates, showing the distribution of light in a vertical plane.

TABULATED DATA INDICATING EFFICIENCY OF COMMERCIAL ELECTRIC ILLUMINANTS SINCE 1878.

These data do not take into consideration color or distribution of light, form of unit and size limitations, cost of lamps, auxiliary apparatus and maintenance, life, convenience of application and all such practical conditions that must be carefully analyzed to make a complete comparison of the useful light-pro-

ducing qualities of different sources. The figures serve to indicate, however, the progress in efficiency that has been made to date since electric illuminants were first commercially used. The last three tabulations give more complete electrical and illumination data of some of the old distinctive types of lamps and also of the very latest practical lighting units.

Solid Conductor Illuminants. (Incandescent Lamps)

(Glass Enclosed)

Type of Illuminant	Amps.	Volts	Watts	Mean Hor. C. P.	Specific Consumption Watts per Mean Hor. C. P.	Total Lumens	Plain Source Lumens per Watt	Commercially Equipped. Lumens per Watt: Metal Reflector	Commercially Equipped. Lumens per Watt: Prismatic Reflector
Carbon Filament (Year 1880) ..	.84	110	92.6	16	5.8	166	1.79	1.08	......
Carbon Filament (Untreated)	.58	110	64	16	4	166	2.60	1.56	......
Carbon Filament (Untreated)	.51	110	56	16	3.5	166	2.97	1.78	......
Carbon Filament (Treated)	.45	110	49.5	16	3.1	166	3.35	2.02	3.00
Osmium Filament (D. C. or A. C.)	1.62	37	60	40	1.5	392	6.5	3.90	......
Tantalum Filament (D. C.)..........	.36	110	40	20	2	198	4.95	2.98	......
Carbon Filament (Metallized)......	.45	110	50	20	2.5	207	4.10	2.5	3.7
Tungsten Filament (Pasted)	.55	110	60	48	1.25	470	7.8	4.7	7.1
Tungsten Filament (Drawn-Wire-Vacuum)	.55	110	60	60	1.0	587	9.8	5.9	8.8
Tungsten Filament (Gas Filled)..	4.35	115	500	714	0.70	7180	14.4	10.1	12.9
Tungsten Filament (Gas Filled)..	6.52	115	750	1154	0.65	11600	15.5	10.8	13.4
Tungsten Filament (Gas Filled)..	8.69	115	1000	1667	0.60	16760	16.8	13.0	15.1
Tungsten Filament (Series-Drawn-Wire-Vacuum)	6.6	15.2	100	100	1.0	992	9.9	9.3	......
Tungsten Filament (Series-Gas Fitted)	6.6	10.8	71.8	100	0.71	1120	15.7	12.7	......
Tungsten Filament (Series-High Current-Gas Filled)	15	13.3	200	400	0.50	3920	19.6	Opal Globe and Reflector 13.25	......
	*6.6—15	32.7	213	400	0.53	3920	18.4	11.80	......
	20	14.1	282	600	0.47	5880	20.9	14.08	......
	*6.6—20	46.2	300	600	.50	5880	19.6	13.2	......
	20	22.5	450	1000	0.45	9800	21.8	14.7	......
	*6.6—20	73.0	474	1000	0.47	9800	20.7	14.0	......

(Open Air Class)

Type of Illuminant	Amps.	Volts	Watts	M. Sp. C. P.	Spec. Con. W. M. Sp. C. P.	Total Lumens	Plain Source L. W.	Commercially Equipped. Lumens per Watt	
Nernst (4 Glower—A. C.)	2.25	220	495	151	3.28	1900	3.8	3.3	......
Nernst (3 Glower—D. C.)	1.20	236	284	88	3.23	1105	3.9	3.4	......

*With auto-transformer.

Gaseous Conductor Illuminants.

(Arc Lamps)

Type of Illuminant	Amps.	Volts	Watts	Mean Spher. C. P.	Specific Consumption Watts per Mean Spher. C. P.	Total Lumens	Plain Source Lumens per Watt	Commercially Equipped. Lumens per Watt
D. C. Open Arc (Carbon) Series "Full Arc"	9.6	50	480	450	1.07	5650	11.8	......
D. C. Open Arc (Carbon) Series "Half Arc"	6.6	50	330	282	1.17	3540	10.7	......
D. C. Open Arc (Carbon) Multiple Series	8	55	440	425	1.04	5340	12.1	......
D. C. Enclosed Arc (Carbon) Multiple	5	110	550	254	2.17	3190	5.8	4.4
D. C. Enclosed Arc (Carbon) Multiple	6	110	660	336	1.97	4220	6.4	4.9
D. C. Enclosed Arc (Carbon) Multiple	3	220	660	175	3.77	2200	3.3	2.6
A. C. Enclosed Arc (Carbon) Multiple	6	104	430	193	2.23	2425	5.6	3.9
A. C. Enclosed Arc (Carbon) Multiple	7.5	104	540	260	2.08	3260	6.0	4.2
D. C. Enclosed Arc (Carbon) Series	5	73	365	231	1.58	2900	8.0	6.1
D. C. Enclosed Arc (Carbon) Series	6.6	77.5	510	395	1.29	4960	9.7	7.4
A. C. Enclosed Arc (Carbon) Series	6.6	77	425	207	2.05	2600	6.1	4.3
A. C. Enclosed Arc (Carbon) Series	7.5	76	480	245	1.96	3080	6.4	4.5
D. C. Mercury Arc (Glass-Low Pressure) Multiple	3.3	110	363	360	1.01	4530	12.5	10.0
A. C. Mercury Arc (Glass-Low Pressure) Multiple	7	110	425	593	0.72	7440	17.5	14.0
D. C. Mercury Arc (Quartz-High Pressure) Multiple	4	110	440	366	1.20	4600	10.4	9.1
D. C. Mercury Arc (Quartz-High Pressure) Multiple	3.5	220	770	1310	0.59	16450	21.4	18.6
D. C. Open Flame Arc-Multiple Series (Inclined Carbons) (Yellow Light)	12	55	660	1557	0.42	19530	29.6	27.2
D. C. Open Flame Arc-Multiple Series (Vertical Carbons) (Yellow Light)	12	55	660	1300	0.50	16300	24.7	22.7
A. C. Open Flame Arc-Multiple Series (Inclined Carbons) (Yellow Light)	12	55	500	1129	0.44	14190	28.4	23.2
D. C. Open Flame Arc-Series (Vertical Carbons) (Yellow Light)	6.6	75-80	510	1425	0.36	17900	35.1	30.2
D. C. Intensified Arc (Multiple)	6	110	660	376	1.76	4720	7.2	5.2
D. C. Enclosed Flame Arc Multiple (Yellow Light)	6.5	110	715	1520	0.47	19050	26.6	21.7
D. C. Enclosed Flame Arc Multiple (White Light)	6.5	110	715	1015	0.70	12730	17.8	14.5

Gaseous Conductor Illuminants—Cont'd.
(Arc Lamps)

Type of Illuminant	Amps.	Volts.	Watts	Mean Spher. C. P.	Specific Consumption Watts per Mean Spher. C. P.	Total Lumens	Plain Source Lumens per Watt	Commercially Equipped. Lumens per Watt
A. C. Enclosed Flame Arc Multiple (Yellow Light)	*7.5-10	110	540	1055	0.51	13250	24.5	20.7
A. C. Enclosed Flame Arc Multiple (White Light)	*7.5-10	110	540	948	0.57	11900	22.1	19.3
D. C. Enclosed Flame Arc Series (Yellow Light)	9.6	50	480	1135	0.42	14250	29.7	21.7
D. C. Enclosed Flame Arc Series (White Light)	9.6	50	480	1040	0.46	13060	27.2	19.8
A. C. Enclosed Flame Arc Series (Yellow Light)	10	60	465	1063	0.44	13350	28.7	24.3
A. C. Enclosed Flame Arc Series (White Light)	10	60	465	933	0.50	11720	25.2	21.4
D. C. Luminous Arc (Magnetite) Series (Long Life Electrode)	4	75-80	310	283	1.09	3560	11.5	10.7
D. C. Luminous Arc (Magnetite) Series (High Eff. Electrode)	4	75-80	310	443	0.70	5560	17.9	17.2
D. C. Luminous Arc (Magnetite) Series (Long Life Electrode)	5	75-80	388	451	0.86	5660	14.6	13.8
D. C. Luminous Arc (Magnetite) Series (High Eff. Electrode)	5	75-80	388	635	0.61	7975	20.6	19.7
D. C. Luminous Arc (Magnetite) Series (Long Life Electrode)	6.6	75-80	510	785	0.65	9850	19.3	18.3
D. C. Luminous Arc Ornamental Series (High Eff. Electrode)	4	80-85	330	422	0.78	5300	16.1	15.1
D. C. Luminous Arc Ornamental Series (Long Life Electrode)	5	78-83	403	426	0.95	5350	13.3	12.5
D. C. Luminous Arc Ornamental Series (High Eff. Electrode)	5	78-83	403	764	0.66	9580	23.8	19.0
D. C. Luminous Arc Ornamental Series (Long Life Electrode)	6.6	78-83	532	912	0.58	11450	21.6	17.1
A. C. Luminous Arc (Titanium Carbide) Series (Experimental)	†6.6-2.8	55-90	230	354	0.65	4450	19.3	......

* Auto-Transformer Type—10 Ampere Arc.

† 2.8 Amps. with Auto-Transformer 6.6 Amp. primary.

Geissler Discharge Class.

Type of Illuminant	Amp.	Volts	Watts	Watts per Foot	C. P. per Foot (Hor.)	Watts per C. P.	S. C. P. per Foot	Watts per S. C. P.	Lumens per Foot	Plain Source Lumens per Watt	Commercially Equipped. Lumens per Watt
A. C. Moore Tube (Yellow Light) Nitrogen Gas 194′ Tube	....	220	4000	20.6	12.9	1.60	10.1	2.05	127	6.2	4.3
A. C. Moore Tube (White Light) Carbon Dioxide Gas 114′ Tube	....	220	3935	34.5	7	4.92	5.45	6.32	68.5	1.99	1.10

Paper No. 142

THE EFFECT OF HYDRO-ELECTRIC POWER TRANSMISSION UPON ECONOMIC AND SOCIAL CONDITIONS, WITH SPECIAL REFERENCE TO THE U. S. OF AMERICA.

By

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To determine in any exact way the result of any particular industry on any period of progress is difficult, because usually many influences contributed to the total results. But we can in a way see the effect of hydro-electric power as a progressive influence by examining the general growth of the country as related to the growth of the electrical industry.

In order not to take a narrow view of the progress, as resulting from the hydro-electric industry alone, it is thought advisable to survey briefly the entire development and the use of mechanical and other power as an aid to man in his quest for the satisfaction of his necessities, his comforts and his luxuries. It will be seen from this view that the aid that man is receiving from hydro-electric power is the end of a long period of development and preparation, from the time when practically all energy was supplied by man's own efforts to the present day, when by far the larger part of the energy required by modern civilization is being received from water-power or from the energy stored in past ages in the form of gas, oil, coal and wood, etc.; and, I believe, the final and ultimate stage of this development is the use of water-power, which is perennial, and not subject to exhaustion; and the use of electric transmission to transmit the energy over wide areas I believe to be as permanent as is the present system of distribution of water under pressure to municipalities. This hydro-electric development had its beginning about 1891 and assumed real headway about 1895, so that the industry may be said to be about twenty years old.

The remarkable results shown would, if understood, make an optimist out of the normal pessimist; and it is believed a general understanding of the reasons for the remarkable developments of the past fifty years, by the nations that were ready for the change, will be of great service in the further work along the new line of general electric transmission and distribution systems.

Man in his native state requires certain necessities to sustain life and reproduce his kind. As he has developed he has added comforts to necessities to satisfy his higher development, and as he became able, he required luxuries to satisfy his vanity and artistic sense. The comforts of one race or person may be luxuries for another. And the luxuries of one may be largely necessary or thought to be necessary for the comfort of another. Thus we find very great discrepancies between the consumption of wealth by one race as compared to another, and also great differences of fortunes of individuals. That these differences are a result of the different capacities of the people and individuals is known, and naturally the differences are greatest when the rapidity of development is greatest. (Social unrest should therefore become less as time goes on.)

It is scarcely necessary to point out that transportation or transmission in one form or another has always been the greatest problem of the world, and that no great progress was made by the human races until they began to classify and organize the labor used in production, and to organize the means of distributing the products of mind and of labor. And, as a matter of fact, no real, lasting progress by the races was made until man began to use other forces than his own muscles to produce the results he wanted.

The first aid man used to relieve his own labor was the energy of animals. This relieved his burden to some extent, allowing more time and energy for other work. But even with this aid there was not the systematic and large development as we know it today. Some races developed well for a time and then decayed. The decay can not always be attributed to lack of brains, for Marcus Aurelius and Confucius and many others, who lived centuries ago, were as sound in their philosophy as we are today, yet Rome decayed and China sleeps with fatigue. Had Rome had modern systems of telephones and telegraph

and used modern transportation and mechanical power, she probably would dominate the World today. And if China had done the work she put on the backs of her people by mechanical power and had used the energy stored by previous ages instead of the energy of her people, she would not have gone to sleep from sheer fatigue. You can not arouse the Chinaman to our normal action, because the elasticity has been taken from his muscles and brain. The same is true of India, Egypt, and many other countries who use their people to supply energy that can be much more efficiently supplied by drawing on nature's stores.

The very rapid growth of the wealth of the world in the past fifty years is not then due, altogether, to our superior brains, but due to the fact that we now do our work largely by energy other than human energy, and the fact that we can now, through a single head, organize and direct energies which in times past would have meant the organization and control of millions of men. The difference in results obtained is due to the fact that we do not need to support these additional workers, but the equivalent energy is taken from nature's stores or from water-power; and also, due to the fact that the mechanical, electrical and chemical operations can now be predicted and realized; but no man in times past could direct the energies of several million men and obtain consistent and efficient results. And, further, many of the results actually obtained by controlling the energies—mechanical, electrical, and chemical—could not be obtained at all by human energy.

Table 1, published by the National Electric Light Association, June convention, 1914, is interesting. Adding the isolated plants, it is estimated that there are 120,000,000 mechanical horsepower in the U. S. (This excludes animal power; and there are about 30,000,000 horses and mules in the U. S.) To exert one horsepower would require the work of ten men and for twenty-four hours it would require at least thirty men, allowing three eight-hour shifts. (A horse can exert for eight hours per day, about 2/3 of a horsepower.)

The 120,000,000 mechanical horsepower in the U. S. are, therefore, equivalent to the work of 1,200,000,000 strong men, assuming only ten men to produce the results of one average horsepower. That means an enormous increase in the capacities of the people and a corresponding reduction in the load

carried by the people. In other words, although we have only 100,000,000 population, we have the equivalent in human workers of twice the combined population of China and India. The actual net results obtained are really greater than the figures shown by the illustration indicate.

And here lies, of course, the fundamental reason for the enormous growth of wealth of the United States and other countries using electrical, mechanical and chemical means of production, and making use of modern methods of supplying energy, in one form or another, to do the work formerly required to be done by men. And here lies largely the reason why we can purchase so many comforts and luxuries, and it is the underlying reason for the large fortunes accumulated in the past fifty years.

Man requires shelter, clothing, food, water, air, light and heat, and energy to supply his modern fundamental requirements. As long as man depended on his own energy and the seasonal products of his labor to supply his wants he could not get more than his necessities. And often in countries like China, India, Egypt, etc.,—where there is a large population and all products are produced by human labor, without much aid from mechanical energy or appliances, and means of transportation are not available for distribution—we have, and must continue to have, repeated famines. That kind of a country does not produce many large or small fortunes, and, necessarily, they never will under present conditions. Any race which lives merely on the local products of the seasons is liable and almost certain to decay. These people make use of only a small part of what they are "heir to from all the ages".

The American Indian had enormous forests, which merely produced for him food and shelter in a limited way, and it took all of his time to provide the necessities for existence. He walked over coal and oil beds, the products of past ages, yet used no coal to heat his home nor oil to light it. He planted few crops and used little energy except his own for his uses.

The modern American who displaced him is collecting "the inheritance of all the ages" by means of modern appliances for utilizing the energy stored by past ages.

To furnish his shelter, he is using the product of the timber age, and has established the large lumber industry as a result

of mechanical means of production, transportation and utilization.

To furnish his clothing and food he is making use of the construction by nature's forces in past ages of enormous valleys to produce his crops. The economical production and transportation and utilization of these crops are a result of the use of mechanical appliances, and other energy than his own is used to furnish the larger part of the energy required.

To furnish light and heat for his home and mechanical power for production and transportation, he is using the products of past and present ages, by using the oil, gas, coal, and water-power to produce what is needed.

Table 1 shows that there are 50,000,000 horsepower in motive-power used for transportation by steam railroads. To accomplish this work by men, if it could be accomplished at all, would require about 500,000,000 men. As a matter of fact, we can not conceive any way of organizing human or animal forces to do this work.

In China, India, Egypt, etc., they use human labor, largely, to do what is done in this country by the railroads, the power systems, the automobiles, the horses and mules, and the millions upon millions of mechanical appliances. The modern nations are using the energy stored in past ages—that is, oil, gas, coal, and wood—to produce this energy. We are, therefore, "collecting our inheritance".

A man, today, controlling and directing wisely the output of one thousand horsepower of mechanical power for eight hours per day is directing the work equivalent of about 10,000 men. Is there any wonder, when viewed from this standpoint, that many fortunes have been produced in this age of the use of mechanical power?

That some have been able to produce larger fortunes than others is largely due to the fact that men have different capacities for seeing new ideas and their probable effect. Some men have large imaginations and keen judgment, and, above all, a capacity for action, and these men usually see the application of any particular development more rapidly than others. These differences of appreciation and knowledge of conditions are greatest, naturally, during the development stages of any large movement, as the use of mechanically applied energy has been in the

past fifty years. Hence, the greatest discrepancies in fortunes are liable to result during the development period. But all the people indirectly gain as a result of the general increase in wealth. For a wealthy man can use little of his wealth, except to use it to build up other industries, which again supply employment for other labor. We could not pay the high wages prevalent in the U. S. were it not for the fact that the development of industries has become possible by using what has been stored by past ages. That is, it is the energy of past ages that is buying our comforts and luxuries, and making us all well off, relatively, to what our condition would be if we did not use this stored energy. There is no reason to believe that we would be any ''better off'' than some of the other nations except for our use of the energies of past ages, made possible by the genius of a few great men.

Think of the labor saved by the modern farming appliances over the original hand spade, scythe and flail. Is it any wonder that fortunes were made by men like McCormick and others, who saw the solution of the problem and did something to solve it? Consider the enormous value of an industry such as the manufacture of farming implements.

Little of this work would have been possible without the modern railroad to transport the crops from points of production to points of consumption. And, naturally, men who saw and solved our railroad problems completely made large fortunes. But what is the fortune of James J. Hill compared to the fortunes he has made for the people of the ''Northwest''?

Consider the value of the telephone and telegraph, and the value of the work of Morse and Bell, in the saving of time and labor and giving us timely information. Consider the lumber, steel, and mining industries, all made practicable as a result of mechanical, electrical, and chemical appliances. All these industries are collecting the fruits of past ages, in the form of wood, iron, oil, coal, copper, silver, gold, etc., by the use of modern chemical, mechanical, and electrical means and appliances; and by the further use of mechanical appliances, we are enabled to have these put in such form and places as we desire for our needs and wants.

Naturally, as we are taking out of the storehouse of nature, we must expect the store's stocks to become exhausted at some

time. Where the stores are very large, or the probability of finding new sources of supply is likely, or other means of supplying the same requirement are possible, we need have no fear for the immediate future. But where we draw from nature's savings bank, we must consider what is left for the future posterity.

The fertility of our soil we know we can maintain by the use of energy to manufacture fertilizers to replace what is taken from the soil; and by the use of energy we can supply the need for the larger part of our work.

As long as a nation can produce energy in a useable form cheaply, I have no fear for its decay. Hence, conversely, the best assurance against decay is a continuous supply of energy that can be produced cheaply. The use of mechanical appliances to replace human and animal energy will largely multiply the capacity of our farms and insure our permanence.

Energies in sufficient quantities to be considered can now be produced by using the energy of gas, oil, coal or water. (We need not consider air or the sun, as these can not be collected in large enough units to be of any value.) The largest amount of mechanical power is now produced by coal or oil, as shown by Table 1. Energy produced by water-power is at this time only about 4% of the total, as shown by this table. And the power transmitted electrically is less than 10% of the total.

With the development of electrical transmission of power from the point of production to the point of consumption a new influence was introduced, which assures our power supply for a very long period, if not indefinitely. By the means of electrical transmission, we can produce the required power at favorable points and transmit the same many miles—and do it efficiently. Thus water-power, and otherwise useless coal beds, may be used to produce the power of the present and future.

Electric generation and transmission of power, be it understood, is merely a medium for conveniently converting mechanical power into electric power and transmitting it from the point of production to the point of use; the original power being divisible into an infinite number of parts, each part performing its function at its proper place in a perfectly predetermined and efficient manner. That is, electric power is a medium of ex-

change of mechanical power, similar to money, which is a medium of exchange of property.

Starting with mechanical power produced by oil, coal, or water-power and converted into the electrical form, we can go on producing forever any mechanical operation; we can fertilize our lands, cultivate them, harvest and transport the crops into market, cook our meals, light, cool and heat our homes, etc., and do it efficiently.

The great problem of all the ages has been to connect the producer and the consumer, and the greatest loss in efficiency is in this step between the producer and consumer. If we could produce, distribute, and consume all other products as efficiently and as simply as we can electricity, this great loss between producer and consumer would largely disappear. For this reason, the electrical method of doing a thing will always be the ideal, and some time in the future a nation's civilization will be measured largely in terms of kilowatt-hours consumed per capita, just as the measure of civilization today is to be largely measured by the amount of mechanical power used. For as the mechanical power is large, so the inefficient labor is small; and a large burden is taken from the people by electric and mechanical power.

As the permanence of water-power and modern electric transmission is assured (we need not consider wireless transmission, as the fraction of one per cent efficiency precludes it) and the sources of production of power by means of oil or coal is assured for a long time—and is assured forever by water-power at high efficiency—we may inquire into the growth of the electrical industry and what has been the effect of this industry on the economic and social conditions of the people.

Table 1 shows the use of about 12,000,000 horsepower in electric generators for central stations and electric railways; this is equivalent to the work of 120,000,000 men. The above is only about 10% of the total mechanical power used in the U. S., as shown by the table, and shows our possibility.

The electrical generator capacity in the United States in 1912, as shown by the tables, was nearly four times as great as that in 1902, showing the high rate at which this form of power is growing. The tables, 2 and 2-b, taken from the U. S. Census for 1912, show the growth of the business since 1902 by in-

stalled capacity and output, etc. Table 3 shows the gross income from these plants.

Mr. T. C. Martin, an authority on electrical statistics, makes the estimate of the gross income from electrical industries for 1914 as equal to $2,265,000,000, as given in Table 4-a. It will be noted that the Central Stations income for the United States is about $4.00 per capita, assuming 100,000,000 people.

Table 4-b shows the motors manufactured in the U. S. as equal to 2,733,418 horsepower for 1909. Table 4-c shows the kilowatt capacity of steam turbines sold by one manufacturer in the United States during the years 1902 to 1914 inclusive. Table 5 shows the summary for all central stations for the United States and Table 7 shows the corresponding growth for California hydro-electric plants. A comparison of the tables is interesting. Table 6-b shows the horsepower installed in the United States and in California in central stations for 1912.

Table 8 showing the available water-power in the United States is extremely interesting. California, Washington, and Oregon have possible water-power of over 10,000,000 horsepower, which at 50% load factor can do the equivalent work of more than 150,000,000 men. Niagara has a possible 6,000,000 horsepower, or at 50% load factor, the equivalent of more than 90,000,000 workers. Future generations will not toil while this power is kept idle mainly for a few tourists. At least the water should be put to work six days in the week, and the sight of the increasing and decreasing quantity as it changed on Sunday would give a very wonderful effect.

California is variously estimated to have water-power resources of between 3,500,000 to 6,000,000 horsepower, and now has developed about 600,000 horsepower. The amount developed is equivalent to 9,000,000 workers, or two workers for each inhabitant, assuming 50% load factor. But, as this was derived from 600,000 horsepower in California and there is a possible use of over 100,000,000 horsepower in the United States, we see that electrical power is truly in its infancy. Table 8 shows available water-power in the United States.

From Table 2-b it is noted that the United States consumed 175.8 kilowatt-hours per capita, which may be increased to 200 kw.-hours per capita on account of isolated plants not given. The kw.-hours output for California, as shown by Table 7, was

practically 10% of the above total for the United States; and as the population is less than 3% of the total for the U. S., it is seen at once that the kw.-hours consumed per capita in California is over 600 kw.-hours per capita. And we know that in California saturation has not been reached.

It is also noted that the kw.-hours output for the United States has increased about four times from 1902 to 1912, but has increased in California nearly twelve times during the same period. As California has been the leader in electric transmission, the hydro-electric growth in California for the past twenty-two years, as given in Table 6, will be of interest. This shows an increase from 643 horsepower in 1892 to 584,511 horsepower in 1914, surely a remarkable result. Table 6-b shows comparison of horsepower installed in central stations in United States and California.

A study of Table 1 will show where the opportunity for further business for the electric station is to be found. Only about 10% of the total shown by the table is now supplied by electric power. The steam railroads total 50,000,000 horsepower and the automobile about one half that amount. That shows wonderful possibilities. How much of the business shown in Table 1 is possible to make electric during the next ten or one hundred years can only be conjectured.

We are certain that at the time when all coal, oil, wood, etc., have been consumed that the only form of power available will be water-power. Water-power is the only permanent useful power which will ultimately be available to us, and as electricity is the ideal system of distributing this power, we see that ultimately all transportation systems will be merely electrically operated mechanical devices for moving those things that can be so moved. That time is close at hand in some localities and further away in others, but I expect to live long enough to see practically all trunk line railroads in this country operated by electric power, the power being generated by water-power, or steam power, using waste coal at large central stations. One example of this is now being put into effect in the Northwest. The roads may not be driven to this condition so much by the cost of moving a given train, but by the fact that the volume of traffic will necessitate that the speed of traffic be increased.

Just as the reciprocating engine men fought in vain against the supremacy of the steam turbine, so the railroad men will fight in vain against the replacement of the steam locomotives by electric traction. The end of the reciprocating engine came in a period of a little over ten years, and when the electric traction really begins to be applied to railroads, I expect to see the end come, not as rapidly perhaps, but as surely as in the case of the reciprocating engine, so far as main trunk lines are concerned where traffic is heavy.

The automobile business for pleasure cars and trucks has been estimated by Dr. Steinmetz to be able to use 1500 to 3000 million kilowatt-hours.

The farmer can also, in many cases with great advantage, use mechanical power where he is now using horses and mules. The 30,000,000 horses and mules in the United States are not an asset where the work done by them can be done by mechanical means at less cost—by doing work with energy taken from oil, coal, or water-power—and it makes room for that many cattle, which are needed for food. It has been estimated that farm horses work only about 11% of the time during their normal life of 90,000 hours.

We will now apply our attention to analyzing some more local California results in order to lead us to understand the cause and probable effect of hydro-electric and other power.

Tables 9-11 show the effect of hydro-electric power on particular industries in California. Particular attention is called to Tables 9, 10 and 11 showing the investment and earnings of power company and consumer's land values as a result of hydro-electric power applied to agricultural development. Tables 10 and 11 show interesting statistics on pumping loads.

As the available arable lands in California have been estimated at 20,000,000 acres, a large part of which must be irrigated by water-power, we see here what enormous values will be produced. Assuming one half of the above lands irrigated by power and using one horsepower to ten acres, we see that a total of 1,000,000 horsepower will be ultimately required.

The production of cement in California has increased from 9500 bbls. in 1896, valued at $28,250, to 6,167,806 bbls. in 1913, valued at $7,743,024. Electric power was used in the

manufacture of all the cement produced in the latter year. The production of gold in California amounted to $20,406,958 in 1913. Of this amount, gold to the value of $8,090,294 was produced by the dredging operations. and the remainder, $12,316,664, came from the mines. All of the dredges and most of the mines used electric power in their operations.

In California one system has grown to have an average load of over 100,000 average horsepower since 1897, serving more than 1,000,000 people in thirty out of the fifty-eight counties of the state, covering an area of nearly 40,000 square miles, or about one-half the size of all the New England States.

I am quite sure that the 300,000 average horsepower now being supplied in California is making a profit for the consumers of more than $50.00 per horsepower or $15,000,000 per year. This profit to the consumer is as large as the gross revenue derived from the power plants proper by all the companies. The cost of power to the consumers has been reduced in California to about one half the cost of twenty years ago. Further than this, the capital saved by the consumers, assuming 600,000 horsepower in motors installed (instead of having to install engine plants), has been at least $30,000,000. This much capital is then available by the power users of California for the development of the industries of the consumers.

Table 4 gives the value of motors manufactured in the United States in 1909 as equal to $32,087,472 for 2,733,418 horsepower. Assuming that each horsepower in motors installed represents a saving of capital for the consumer of $50.00, the total capital saving, as a result of installing motors instead of engines, represents a capital saving of $136,655,000 for the one year of 1909. Think of the tremendous advantage, especially to the small manufacturer.

Statistics might be quoted almost indefinitely, but enough has been shown to indicate the value of electricity in this new era of development. Cost of electric lighting has been reduced about 75% in the past 20 years, as a result of a reduction of power production due to water-power and steam turbine improvements and increase of lamp efficiency. In the same time, cost of living and farm labor increased about 50%.

It has been shown by these statistics that these large elec-

tric-power systems are to the advantage of the community as a whole, and a few simple considerations have shown that electricity is one of the greatest influences for the stability of a country; for, as is well known, to be stable, a country must be efficient, and it is now being more and more recognized that to be efficient it must use electric power. Also, it is now becoming recognized that the most stable country is one in which the industries are diversified and widely distributed, and, especially, one having a prosperous and stable farming interest. To bring about this diversification and distribution of interests and population the influence of the electric-power systems (and especially the water-power systems) is probably as great as that of the railroads.

The stability of any civilization depends, also, on the fact that it consumes less than it produces; and as it is necessary, with an increasing population (the natural resources of a country being fixed and limited and its population increasing), to operate more and more efficiently in order to produce more than is consumed, the most efficient methods must be employed for all operations. Nature's naturally replenished sources of power must be used instead of consuming wood, coal, oil, etc.; and the most natural source of power is falling water, which nature is annually reproducing.

This water-power, converted into the electric form for distribution and supplied to electric appliances for conversion into the form desired, at the place desired, is the most efficient and convenient system imaginable; and the electric method of doing a thing also tends, inherently, to remain efficient, for inefficiency makes its appearance as heat, and heat means trouble in the electric system, and as the human being wants to avoid trouble there is inherent reason for efficiency.

Let us repeat, the great problem of all ages has been to connect the producer and the consumer, and the greatest loss in efficiency has been in this step between the producer and the consumer. If we could produce, distribute, and consume all other products as efficiently and as simply as we can electricity, this great loss between production and consumption would be largely reduced. For the reason of the high inherent efficiency, the electrical method of doing a thing will always be the ideal; and some time in the future, a nation's

civilization, as has been said, will be measured largely in terms of kilowatt-hours consumed per human being per year, because as the kilowatt-hours are large, so the non-productive inefficient labor will be small. Therefore, a nation having large natural water-power need never fear decay. Hence we see the general benefits accruing to all the people—an unearned increment, so to speak—as a result of the electric transmission systems. The electrical transmission systems will ultimately form a net work all over the country, just as the railroads have gridironed the states in the past, and electric service will be necessary for economic farming, manufacturing, mining, etc.

The result of a general electric-power system will be that the same service, in electric power, will be available at the mining camps in the mountains, at the small towns, and to the industries in the larger cities. Aside from the economies mentioned of such a system, resulting from the concentration of the facilities, the power conditions throughout the country will tend to become equalized, resulting in a distribution of population and industries not otherwise possible; and resulting, also, in adding to the general stability of the country and in great saving in capital and operating expenditures for the industries and cities served. Very often it will enable the establishment of an industry, for example, a small factory, a rock quarry, a cement plant, a farm, at a point otherwise prohibited, thus adding to the economic value of the district. The tendency will also be to equalize rates for light and power and to reduce rates to the lowest level, as is evidenced by the fact that in small California cities the consumer of electric light or power gets a much lower rate than is ordinarily obtained in Eastern cities having local power stations. Electric service to farmers is almost unknown in the East.

In consequence of this electrical development, industries will be established in many of the smaller towns and outlying districts where the employees can live more advantageously, as is being done in California; and the natural, effective result is a healthy growth of all parts of the state and country; a large saving in operating expenses, capital and resources; a general equalizing of opportunities; and on the whole, a tremendous economic gain for the communities, increasing in

geometric ratio. It is naturally to the interest of the people that the power systems be extended as rapidly as conditions warrant, as the resultant economies from the extension of the business will of necessity redound to their benefit. For this reason, as I have said before, California or any other state or nation having available cheap power need never fear decay.

Also a nation using science and mechanical power to solve its problems tends to become exact, and draw conclusions as to probable results; and if anything will teach a man that action is necessary to get results, it should be obtained from mechanical and electrical power appliances.

The transmission and distributing systems are gradually covering the entire state and will ultimately form an electrical, metallic screen over the entire country. This will be a screen of equal and constant potential, under which service, opportunities, and rates tend to become equal. By building the transmission systems across and through valleys of California, there was formed a system which makes for the uniform and stable development of the state as a whole; the same will occur in other sections of the United States. Not only this, but the hydro-electric companies, and those using waste coal, use a waste to reduce a want, and in using this waste energy to lift the burdens of humanity they make a net gain for civilization and do not merely transfer a burden from one set of shoulders to another. That is, electric power tends to make masters of men and to eliminate slavery. This gives us assurance for the future, for an increasing population requires progress, progress requires profits, profits require efficiency—and we may claim, in all modesty, that modern business could not be carried on efficiently without electric power.

The statistics given, with a backward look over the road which has been traveled in the past fifty years, make one hesitate to predict the ultimate effect of a general electric-power transmission on the future civilizations. We have, however, summed up the general benefits to be derived.

The great benefits derived by the people as a result of the electric railways in making it possible for people to live in suburbs instead of in the tenement houses in cities, is only comparable to the general benefits derived by all in the use of electricity in the home as well as in the factory and farm.

The further extension of the electric railways depends largely on the establishment of the large central stations and transmission systems.

In a paper on "High Potential, Long Distance Transmission and Control" which I read at the International Electrical Congress at St. Louis in 1904 I said, "At the present time 60,000 volts can be safely handled and 80,000 volts is not out of reach by those experienced; and judging the future by the past we may expect to reach 100,000 operating voltage in a few years".

We are already 50% in excess of the above voltage, and there is no reason to believe we could not design a system for double present voltage if there was the demand for it, and I believe the demand is inevitable in the near future.

I expect to see central stations of 100,000 kw. with 25,000 kw. units become common, and I expect to see trunk transmission lines constructed to connect a large number of these stations throughout the country, with branch substations and lines extending practically over the entire country. The prime movers for the generators will be so large as to exclude reciprocating engines of every kind, limiting the prime movers to water-wheels located at favorable water-power sites and steam turbines located at sources of cheap fuel, coal, oil or gas.

When this is accomplished and the energy we require comes from water-power and waste fuel sources, we will have reached the age of the wise use of "our inheritance". The curve of human efficiency must become flattened and become asymptotic to the line representing 100%, and as this 100% line is known, and we are approaching it with the electric system, I believe the electrical age to be the ideal end of the remarkable series of steps of human progress that has taken place in the past 100 years.

I expect to see the consumers in small towns and the farmers in our Western valleys not only light their homes and cook their meals with electric power, but also cool their homes in summer and heat them in winter by the use of a system of energy storage. With the addition of the modern highways and the use of automobiles, the rural life will then have enough attractions to solve the "back to the farms" movement.

APPENDIX.

Table 1. U. S. Mechanical Horsepower

From Bulletin N. E. L. A. by T. C. Martin.

Manufactures:		
Steam	16,400,000	
Water	1,900,000	
Other	1,100,000	
Total		19,400,000
Central Electric Light and Power Stations:		
Steam	5,000,000	
Water	2,600,000	
Gas	100,000	
Total		7,700,000
Street and Electric Railways:		
Steam	3,100,000	
Water	300,000	
Total		3,400,000
Steam Railroads (locomotives only)		50,000,000
Steam and naval vessels		4,000,000
Mines and quarries		5,000,000
Custom flour, grist and saw mills (not included in U. S. Census of manufactures)		1,000,000
Irrigation		400,000
Total		90,900,000
Automobiles		22,500,000
Total including automobiles		113,400,000

"The closeness of these figures may be guaranteed in a way by the fact that the United States Census figures for central stations in 1912 show a total of 7,526,938 horse-power and those of the electric railways 3,680,051, or a grand total of 11,206,989".

Table 2-a. Central Electric Stations and Electric Railways. Number, Kind, and Kilowatt Capacity of Dynamos: 1912, 1907, and 1902.

United States Census, page 16.

	Total		Kind of Dynamos					
			Direct current, constant voltage		Direct current, constant amperage		Alternating and polyphase current	
	Number	Kilowatt capacity	Number	Kilowatt capacity	Number	Kilowatt capacity	Number	Kilowatt capacity
Total								
1912	15,393	7,642,755	4,967	1,161,213	820	82,152	9,606	6,399,390
1907	15,297	4,432,641	5,872	1,347,962	1,685	80,992	7,740	3,003,687
1902	15,786	2,110,597	6,684	1,055,411	3,539	145,866	5,563	909,320
Central Stations								4,661,199
1912	12,597	5,134,689	3,401	429,662	745	43,828	8,451	
1907	12,173	2,709,225	3,680	406,460	1,685	80,992	6,808	2,221,773
1902	12,484	1,212,235	3,823	330,065	3,539	145,866	5,122	736,304
Electric Railways								
1912	2,976	2,508,066	1,566	731,551	75	38,324	1,155	1,738,191
1907	3,124	1,723,416	2,192	941,502	*	*	932	781,914
1902	3,302	898,362	2,861	725,346	*	*	441	173,016

* Not reported separately.

(Table continued on following page)

Table 2-a—Continued. Central Electric Stations and Electric Railways. Number, Kind, and Kilowatt Capacity of Dynamos: 1912, 1907, and 1902.

United States Census, page 16.

Percent of Increase[1]

	Total		Kind of Dynamos					
			Direct current, constant voltage		Direct current, constant amperage		Alternating and polyphase current	
	Number	Kilowatt capacity	Number	Kilowatt capacity	Number	Kilowatt capacity	Number	Kilowatt capacity
Total								
1902-1912	— 2.5	262.1	—25.7	10.0	—76.8	—43.7	72.7	603.8
1907-1912	†	72.4	—15.4	—13.9	—51.3	1.4	24.1	113.1
1902-1907	— 3.1	110.0	—12.1	27.7	—52.4	—44.5	39.1	230.3
Central Stations								
1902-1912	0.9	323.6	—11.0	30.2	—78.9	—70.0	65.0	533.1
1907-1912	3.5	89.5	— 7.6	5.7	—55.8	—45.9	24.1	109.8
1902-1907	— 2.5	123.5	— 3.7	23.1	—52.4	—44.5	32.9	201.7
Electric Railways								
1902-1912	—15.3	179.2	—45.3	0.9	....	....	161.9	904.6
1907-1912	—10.5	45.5	—28.6	—22.3	....	....	23.9	122.3
1902-1907	— 5.4	91.8	—23.4	29.8	....	....	111.3	351.9

[1] A minus sign (—) denotes increase.

† Less than one-tenth of 1 percent.

Table 2-b. Central Electric Stations and Electric Railways. Output of Generating Stations: 1912, 1907, and 1902.

U. S. Census, page 17.

	Kilowatt Hours		
	1912	1907	1902
Total	17,585,662,014	10,621,406,837	4,768,535,512
Central stations, total	11,532,963,006	5,862,276,737	2,507,051,115
Commercial	10,995,436,276	5,572,813,949	2,311,146,676
Municipal	537,526,730	289,462,788	195,904,439
Electric Railways	6,052,699,008	4,759,130,100	2,261,484,397

Percent of Increase.

	1912	1907	1902
Total	268.8	65.6	122.7
Central stations, total	360.0	96.7	133.8
Commercial	375.8	97.3	141.1
Municipal	174.4	85.7	47.8
Electric Railways	167.6	27.2	110.4

Table 3. Commercial Central Electric Stations: 1912, 1907, and 1902.

U. S. Census, page 14.

	1912	1907	1902	Percent of increase: 1902-1912
Number of stations	3,659	3,462	2,805	30.4
Total income	$278,896,610	$161,630,339	$78,735,500	254.2
Light, heat and power including free service	$264,317,150	$156,000,257	$77,349,749	241.7
All other sources	$ 14,579,460	$ 5,630,082	$ 1,385,751	952.1
Total expenses including salaries and wages*	$217,502,313	$123,880,291	$62,835,388	246.1
Total number of persons employed	71,395	42,066	26,909	165.3
Total horse-power	6,969,320	3,776,837	1,685,020	313.6
Steam engines and steam turbines †				
Number	5,820	6,268	5,199	11.9
Horse-power	4,539,866	2,408,351	1,246,642	264.2
Water Wheels				
Number	2,664	2,328	1,308	103.7
Horse-power	2,340,820	1,318,740	427,254	447.9
Gas and oil engines				
Number	833	385	147	446.7
Horse-power	88,634	49,746	11,224	689.7
Kilowatt capacity of dynamos	4,766,012	2,500,209	1,098,855	333.7
Output of stations kilowatt hours	10,995,436,276	5,572,813,949	2,311,146,676	375.8
Estimated number of lamps wired for service				
Arc	413,544	‡479,260	334,903	23.5
Incandescent and other varieties	69,449,293	‡37,786,435	16,616,593	318.0
Stationary motors served				
Number	413,578	162,677	99,102	317.3
Horse-power capacity	3,966,328	1,617,337	434,681	812.5

* In addition to salaries and wages, includes the cost of supplies and materials used for ordinary repairs and replacement, advertising, fuel, mechanical power, electrical energy purchased, taxes, and all other expenses incident to operation and maintenance, and for 1912 charges for depreciation and charges for sinking fund.

† Includes auxiliary engines.

‡ Includes, for purposes of comparison, 6,487 arc and 239,418 incandescent lamps reported by the electric companies to light their own properties. Lamps for such service were included in the total number reported 1912.

Table 4-a. Gross Income, Electrical Industries, 1914.

(T. C. Martin, Elec. World, Jan. 2, 1914.)

Electrical manufacturing	$450,000,000.00
Electric railways	730,000,000.00
Central stations	400,000,000.00
Telephone service	350,000,000.00
Telegraph service	85,000,000.00
Isolated plants	125,000,000.00
Miscellaneous	125,000,000.00
Total	$2,265,000,000.00

The total value of agricultural products in 1910 was about four times the above. The gross earnings of the railroads in the United States in 1907 was about equal to the above earnings of the electrical industries in 1914 and thirty years earlier, or in 1878, the earnings were about $490,-000,000 for the railroads. In 1830, there were but 23 miles of railroads in the U. S. The total value of leading manufactured products was about 20,000 million dollars in 1909. See statistical Atlas U. S. Plate 414. The total electrical manufactured products being about $221,000,000.00 for 1909.

Table 4-b. Number, Capacity and Value of Electric Motors Manufactured in 1909, 1904, 1899.

U. S. Census, Bulletin Manufactures, 1910.

	Census	Number	Horsepower	Value
Motors, total	1909	504,030	2,733,418	$32,087,482
	1904	206,343	1,493,012	22,370,626
	1899	159,780	1,221,482	19,505,504
For industrial power	1909	243,423	1,683,677	18,306,451
	1904	79,877	678,910	13,120,948
	1899	35,604	515,705	7,551,480
For railways and miscellaneous uses, including value of parts and supplies for all motors	1909	53,710	795,652	9,847,487
	1904	20,779	750,001	7,290,266
	1899	23,179	678,061	8,182,724

The number, capacity, and value of motors for transforming electric current into mechanical power were very much larger in 1909 than in 1899. The number of motors of all kinds produced increased 215.5 percent during the decade, their capacity 123.8 percent, and their value 64.5 percent. The largest increases are shown in the case of the motors operating stationary machinery, which are designated in the table as motors for industrial power. During the decade ending with 1909 the number of these motors for distributing power to be used industrially increased 583.7 percent, and their value 142.4 percent. The average capacity of these motors decreased from 14 horsepower in 1899 to 7 horsepower in 1909. Of the motors designated to be used for industrial purposes the largest increases are shown in the case of those operated by alternating current. The total capacity of such motors increased from 137,376 horsepower in 1899 to 1,006,995 in 1909, though the average capacity per machine decreased from 23 horsepower in 1899 to 7 horsepower in 1909.

Table 4-c. Kilowatt Cap. Steam Turbines Sold by One Manufacturer in the United States.

1902	97,000	1909	325,797
1903	101,230	1910	721,338
1904	94,855	1911	375,728
1905	239,780	1912	700,160
1906	274,460	1913	610,117
1907	286,320	1914	302,183
1908	241,134		

The cost of steam-power installations decreased about 33% from 1905 to 1915.

The cost of operation decreased about 30% in the same period.

The above was due to the steam turbine improvements and naturally hydro-electric power must be sold for less than steam-power.

Table 5. Summary for All Central Electric Stations and Hydro-electric Station Reporting Water Power of 1,000 Horsepower or More: 1912.

U. S. Census, page 21, Bulletin 124.

	Total for central electric stations	Stations reporting water power of 1000 horsepower or more	Percent of total
Number of stations	5,221	225	4.3
Cost of construction and equipment	$2,175,678,266	$922,954,341	42.4
Total income	$302,115,599	$72,717,582	24.1
Light, heat and power, including free service	$286,980,858	$66,852,631	23.3
All other	$15,134,741	$5,864,951	38.8
Total expenses, including salaries and wages	$234,419,478	$56,342,064	24.0
Total number of persons employed	79,335	17,160	21.6
Total horsepower	7,528,648	3,179,244	42.2
Steam engines and steam turbines:			
Number	7,844	520	6.6
Horsepower	4,946,532	885,162	17.9
Water-wheels:			
Number	2,933	1,552	52.9
Horsepower	2,471,081	2,288,396	92.6
Gas and oil engines:			
Number	1,116	19	1.7
Horsepower	111,035	5,686	5.1
Kilowatt capacity of dynamos	5,134,689	1,951,397	38.0
Output of stations, kilowatt hours	11,532,963,006	5,859,397,943	50.8
Estimated number of lamps wired for service:			
Arc	505,395	62,624	12.4
Incandescent and other varieties	76,507,142	13,403,893	17.5
Stationary motors served:			
Number	435,473	73,645	16.9
Horsepower capacity	4,130,619	1,283,769	31.1

Table 6-a. Horsepower in Hydro-electric Plants in California.

1892	1 plant	480	K.W.	equal	643	H.P.
1893	2 plants	1,230	"	"	1,649	"
1894	2 "	1,230	"	"	1,649	"
1895	4 "	5,730	"	"	7,681	"
1896	7 "	8,190	"	"	10,978	"
1897	9 "	12,440	"	"	16,676	"
1898	15 "	20,715	"	"	27,768	"
1899	19 "	27,175	"	"	36,427	"
1900	20 "	28,695	"	"	38,478	"
1901	23 "	38,015	"	"	50,958	"
1902	27 "	51,565	"	"	69,122	"
1903	33 "	65,075	"	"	86,232	"
1904	41 "	88,465	"	"	118,586	"
1905	50 "	100,115	"	"	134,216	"
1906	54 "	122,265	"	"	163,894	"
1907	58 "	161,465	"	"	216,441	"
1908	67 "	238,985	"	"	320,355	"
1909	69 "	248,285	"	"	332,808	"
1910	71 "	293,095	"	"	392,889	"
1911	71 "	293,095	"	"	392,889	"
1912	72 "	308,295	"	"	413,264	"
1913	78 "	420,045	"	"	563,063	"
1914	79 "	436,045	"	"	584,511	"

Table 6-b. Commercial Central Electric Stations in United States and California: 1912.

	United States	California	% Calif.
Total horsepower	6,969,320	838,693	12%
No. of units	9,317	365	
Total steam engines	1,585,583	103,296	6.5%
No. of units	4,898	98	
Total steam turbines	2,954,283	303,105	10.5%
No. of units	922	54	
Total water-wheels and turbines	2,340,820	430,312	18.4%
No. of units	2,664	202	
Total gas and oil engines	88,634	1,980	2.6%
No. of units	833	11	

Note: California had less than 3% of United States population in 1912.

Table 7. Commercial Central Electric Stations in California: 1912, 1907 and 1902.

Bulletin 124, U. S. Census, page 30.

	1912	1907	1902	Percent of increase 1902-1912
Number of stations	112	129	115	
Total income	$27,685,573	$14,416,529	$5,066,417	447
Light, heat and power, including free service	$ 1,224,419	$ 494,501	$ 120,327	920
Total expenses, including salaries and wages	$22,803,526	$12,580,937	$ 3,918,975	482
Total number of persons employed	5,738	3,128	1,360	248
Total horsepower	848,248	384,673	34,224	532
Steam engines and steam turbines				
Number	169	201	194	
Horsepower	414,206	159,644	55,237	650
Water wheels				
Number	205	172	133	54
Horsepower	432,062	208,444	78,933	447
Gas and oil engines				
Number	11	11	6	83
Horsepower	1,980	16,585	618	220
Kilowatt capacity of dynamo	588,281	238,480	78,933	602
Output of stations, kw-hours	1,747,459,041	661,606,309	152,728,042	1,034
Estimated number of lamps wired for service:				
Arc	24,890	19,691	15,764	58
Incandescent and other varieties	6,793,200	3,068,214	1,006,875	575
Stationary motors served:				
Number	29,059	11,560	5,190	459
Horsepower capacity	603,742	200,067	50,296	1,102

Table 8. Potential Water-power in the United States.

As computed by the United States Geological Survey and as revised by the Bureau of Corporations. Page 55.

	Potential horsepower on basis of 90 percent efficiency		Potential horsepower on basis of 75 percent efficiency	
	Minimum	Assumed maximum	Minimum	Assumed maximum
United States	32,083,000	61,678,000	26,736,000	51,398,000
Summary				
North Atlantic States	2,670,000	4,910,000	2,223,000	4,092,000
South Atlantic States	2,813,000	5,107,000	2,344,000	4,256,000
North Central States	2,079,000	4,270,000	1,733,000	3,558,000
South Central States	1,726,000	3,342,000	1,438,000	2,785,000
Western States	22,795,000	44,049,000	18,996,000	36,707,000

"A notable fact disclosed by the table is the remarkable natural centralization of water-power in the United States. Approximately 11,500,000 h.p. (on the 75 percent efficiency basis), or 43 percent of the total estimated minimum power of the country is found in the States of California, Oregon and Washington alone. If we add to this total the power of the three states of Montana, Idaho, and Wyoming, we have in the six states 60 percent of the total power, and by including the three states of Colorado, Arizona, and Utah, we find in the nine states mentioned 70 percent of the estimated minimum power in the United States. About 8 percent of the minimum total is found in the territory in the northeastern section of the country, including Pennsylvania and the states to the north and east. In the area east of the Mississippi River and south of the Ohio River there is about 12 percent. These three groups of states contain about 90 percent of the estimated minimum water-power of the country, and more than one-third of the remainder is in the four states of Michigan, Wisconsin, Minnesota, and Illinois, bordering on the Great Lakes". Extract from Commissioner's Report.

Table 9. System of Mt. Whitney Power and Electric Company: 1909, 1914.

	Total Value of Company's property December 31st, 1915	Total Assessed Valuation, Tulare County	Gross Earnings of Company
1909	$3,622,828.46	$41,241,226.00	$278,872.78
1910	3,751,856.25	37,445,140.00	336,945.15
1911	3,896,104.64	39,552,703.00	388,939.87
1912	4,559,235.78	40,271,948.00	445,826.39
1913	5,150,818.30	46,842,975.00	562,852.29
1914	5,615,181.52	48,840,387.00	643,728.52

	Total K.W.H. Generated	K.W.H. Generated Maximum Month	Maximum Demand on Power Houses
1909	14,200,600	1,911,980	
1910	15,415,910	2,147,500	
1911	19,850,678	2,660,000	
1912	25,868,696	3,357,420	5,548 K.W.
1913	39,414,770	5,371,400	9,145 "
1914	45,687,700	5,974,700	9,225 "

The Census Bureau estimated that the gain in farm values in Tulare County from 1900 to 1910 was $56,251,841. A large part of this gain was due to the introduction of electric power in the district for pumping purposes.

Table 10. Acreage Used for Various Crops. System of Mt. Whitney Power and Electric Company.

Citrus	21,680¾	acres	(10,495 acres bearing)
Alfalfa	19,779½	"	
Miscellaneous field crops	3,666½	"	
Olive orchards	1,664½	"	(211½ acres bearing)
Vineyards	814	"	
Miscellaneous orchards	792¼	"	
Peaches	758	"	
Total Acres Irrigated	49,155½	"	
Total area in district boundaries	853,700	acres.	

Table 11. Percent of Horsepower Used for Various Purposes. System of Mt. Whitney Power and Electric Company.

Agricultural	81.0%
Industrial	8.9%
Domestic	4.5%
Railroad	2.8%
Miscellaneous	2.8%
	100.0%

The above shows the possibilities of the application of power to pumping for irrigation. Much larger areas have been reclaimed by pumping surplus water off the lands, in other sections of the state.

It is estimated that 90,300 horsepower in motors are sold yearly in California, of which 55% are for agricultural development.

Note: The system of the Mt. Whitney Power and Electric Company has been chosen to illustrate the agricultural development as a result of electric power because of the fact that it has the largest percentage of agricultural load of any system in existence. This company illustrates the effect of agricultural loads on the power business of the company as well as the effect of the electrical development upon agriculture.

DISCUSSION

Mr. Hays. **Mr. John Coffee Hays,*** Mem. A. I. E. E., desired to say that the Mt. Whitney Co.'s figures in this paper are not quite fair examples of what might be expected from an ordinary plant supplying an agricultural community. The hydro-electric feature is only a small factor in the success of the company. The greatest factor is the ability of the commercial department. Had the Mt. Whitney Co. or the San Joaquin Co. been content to take the business as presented, they would never have made the showing they now make.

The Mt. Whitney Co. must frequently advance capital for lengthy periods on the notes of consumers; that is, it must act as banker. During the past two years the alfalfa produced on 20,000 acres was a drug on the market. The citrus business also has not been good. During such periods, the company must carry many men over on their power bills.

He did not believe that there is much "cheap" hydro-electric power in California. The power house ready to use is only a very small part of the system. Professor Cory states that gross earnings of California hydro-electric power companies are less than 25% of the investment and reduce to less than 12½% for the net income. There is, therefore, very little margin, evidently, from which to pay dividends. He felt sure that no water power can be developed in California for less than $200 per h.p. None at present have cost less and the cheapest would naturally be

* President, Mt. Whitney Power & Electric Co., Visalia, Calif.

developed first. Today, the modern steam plant would run water power a close race. Mr. Hays.

He wished to call attention to Table 7. This shows 843,000 h.p. costing $169,000,000. The gross income is 16% and the net income, available for dividends, is only 3%. Prof. Cory gives figures from an automobile plant receiving $95,000,000 gross income on a $15,000,000 investment.

Mr. J. B. Fisken,* Fel. A. I. E. E., wished to call particular attention to page 251 of this paper, where Mr. Baum tells of the discovery of something that the regulatory State Commission seems to have overlooked, namely, the profit to the consumer. If the commissions in the various states could be made to realize that there is actually such a profit, it is possible that they might allow this profit to be reflected in the power rates, and some utilities that are being persecuted almost to the point of bankruptcy might be able to live. The tying together of electric power systems, he states, is generally recognized as an economic practice. His company has already tied in to one neighbor and will soon tie in to another. However, it will probably never be tied in with municipal plants. The sad fact is that politics enter into every operation and they cannot produce the results. Last year, in talking with business men in Canada, he discovered that they regarded the Hydro-Electric Power Commission of Ontario as "unfortunate" and an economic failure. Mr. Fisken.

The cost of supplying the power to small consumers is largely in the distribution. Until distribution costs can be reduced, the small consumer may be, and frequently is, supplied at a loss. The small consumer cannot be supplied with a service for less than, say, $1 to $1.25 per month, whereas a 70c per month minimum rate is established by the regulatory body for his Company. The construction rules in Washington are very absurd since the 1913 code has been enacted, and distribution costs have been increased about 25 percent, without benefit to the utilities, the consumer or the public.

* Washington Water Power Co., Spokane, Wash.

Paper No. 143

ELECTRIC POWER IN CANADIAN INDUSTRY.

By

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Electricity maintains its commercial supremacy as a source of energy, to the general public, as a convenience; to the manufacturer requiring a source of power, on account of its adaptability to his respective needs and by its economy in application; in the field of traction, by its operative simplicity, cleanliness and comparative silence and suitability to frequent short haul; to the electrometallurgist and electrochemist, by permitting of concentration of energy, simplification of processes and equipment, for its uniformity and control of results, and from its application in the production of materials unavailable from any other source. In communication and in therapeutics its field is absolute. Dominating all these elements of industrial power supremacy, cheapness of electrical energy is paramount.

In the study, from the Canadian standpoint, of the use of electric power and its generation and supply, it is necessary to analyse the make-up of the typical power load, such as may be found to comprise the greater portion of the aggregate loads throughout the Dominion.

In general, a mixed power load consists of domestic, industrial or power load, municipal service, commercial lighting and street lighting. The domestic load has, by energetic campaigning by the power distributing companies, been constructed into one involving no mean figures; the former incandescent-

lighting load, generally to be found in meagre quantities, even ten or fifteen years ago, has been greatly amplified, so that the unequipped and unlighted residence, anywhere throughout the Dominion within reach of electrical sources, has become the exception; the day load of the many household electrical accessories and conveniences has appreciably added to the consumed power, tending to flatten out the peaked curve of this load and extend the service hours of the distribution system and transformers over a longer remunerative period and, further, get fuller advantage of power purchased on a peak load basis. The non-load night hours are now engaging the attention of the central station, with the hope of commercially establishing electric heating accumulators for charging during such hours. As yet, it is the experience that lighting and domestic loads create a peak in early evening, unapproached by any other loads on domestic service transformers.

While the domestic service loads cannot be termed industrial loads, the subject this paper is more properly confined to, examples of loads to be quoted herein are appreciably composed of domestic loads, and, in most cases, the present power service originated many years ago from the immediate prospect of this market alone. Today, it is usually the personal aspect and home convenience of electrical power that carries the great weight in the establishment of a publicly-owned system or in the granting of service franchises. Directly and indirectly, domestic electrical-power service bears a most important relationship to electricity in industry.

For municipal uses such as pumping and street lighting electricity is universal. Off-peak-hour pumping into water reservoirs has proven an economical system when operated as a component of a mixed power load. The enormous strides in application and design of street-lighting units and the great efficiency to be obtained have placed electrical street lighting far beyond the reach of any other illuminating source.

Electric power in industry has a wide and practically limitless field. As a motive power available in any capacity, conveniently and economically applicable in every class of service, it out-ranks all its competitors, from the rolling-mill steam engine, reversing its ponderous thousands of horsepower, to the

infinitesimal foot-power of a sewing machine. In the heating and welding of materials, as a part of the process of manufacture, electricity, by its control, speed and concentration or distribution, enjoys a peculiar field, distinct from either coal or gas.

Electric railways have not reached beyond the industrial, urban, interurban and terminal use. The electrification of trunk lines, which awaits the supply of economic electric power at frequent intervals along the route and the overcoming of the many necessary minor changes in trunk line operation, besides the enormous capital outlay required, comprise a combination of requirements not considered economically attractive as yet.

Electrometallurgy and electrochemistry have been responsible for the handling of materials not workable by any other means, have made available new materials and have greatly cheapened the production of many important materials of wide use. Aluminum, calcium carbide, chromium, cyanamid, silicon, etc., are products only from electrical processes. Alkalies, hypochlorite, phosphorous, magnesium, sodium, nitrates, etc., are produced electrically at the lowest cost.

In telephony and telegraphy; radio-telephony and radiotelegraphy; radiography and therapeutics, electricity, while possibly providing the greatest conveniences and aids afforded to mankind is not of such power-consuming magnitude as to require further mention.

The source of electric power for commercial purposes is motive power produced by steam, oil, gas or water. In Canada, it is notable that, without exception, all cities are now supplied by or are within the economic distribution zone of hydro-electric sources, and, further, commercial conditions are such that power from these sources is available to the customer at very attractive rates and it is apparent that the future of power-consuming industries has its foundation in the bountiful and wide-spread water power resources of the country.

The Dominion of Canada has an area of 3,729,700 square miles, stretching from the Atlantic to the Pacific and from the northern boundary of the United States to the Arctic Ocean.

The Northwest Territories, the vast northern portion of Quebec and the greater part of the Yukon cannot be considered, within our generation, to be factors in the industrial field. The possibilities in these districts, from the standpoint of natural resources, are not as yet, with the incomplete investigations made up to the present, capable of appreciation; water power is plentiful, but so remote from any present market that the capacities of the thousands of known water powers are not included in statistics; within a limited area, the Yukon is an exception. In the Provinces of Nova Scotia, New Brunswick, Prince Edward Island, Quebec, Ontario, Manitoba, Saskatchewan, Alberta and British Columbia, power is available in great abundance.

Nova Scotia water powers are, in general, of small dimension, as a result of the limited drainage areas and the low available heads on the various rivers, due to the general topography of the country. New Brunswick has many rivers of magnitude, but with gradual drop and small facilities for storage. Prince Edward Island is very limited in water powers, there being no site capable of the development of over one hundred horsepower. Quebec and Ontario and the eastern and northern portions of Manitoba have enormous possibilities in power production, while the southwestern part of Manitoba, southern Saskatchewan and southeastern Alberta are quite limited in capacities, being the prairie, wheat-growing ''West'' of Canada. The Rocky Mountains and eastern foothills in Alberta provide a notable source of power and the Province of British Columbia, comprising the western slope of the Rocky Mountains to the Pacific Ocean, is capable of enormous water-power development.

Within the provinces of the Dominion of Canada, and excluding the Northwest Territories, practically all of the Yukon, and the northern and eastern portions of Quebec, it is estimated that 17,764,000 horsepower are available, this amount being inclusive, in the case of Niagara Falls, Fort Frances and the St. Mary's River at Sault Ste. Marie, of only the development permitted by international treaties, and, further, does not contemplate the full possibilities of storage for the improvement of capacities. The developed powers, which are inclusive of all

water powers, whether for electrical production, pulp grinders, for milling or for the great many other uses, aggregate 1,712,-193 horsepower, as developed by turbines, and this amount is distributed over the Provinces as shown in the following table:

Province	Horsepower Developed
Nova Scotia	21,412
New Brunswick	13,390
Prince Edward Island	500
Quebec	520,000
Ontario	789,466
Manitoba	56,730
Saskatchewan	45
Alberta	33,305
British Columbia	265,345
Yukon	12,000
Total	1,712,193

The relation between population and water power developed makes a very interesting study. It cannot be said that a definite relation exists or should exist, although it is possible that in the future, as the rapidly changing commercial conditions assume a permanent stability from established markets and universal demand, a constant may be deduced for the equation, the variables being environment, government policy, inherent commercial instinct, natural resources of materials, accessibility of market and, above all, available sources of low-cost electric power.

Horsepower per capita of the various manufacturing countries may be compared on the present standing, and while the contemporary industrial conditions may not readily admit of the projection of these values to the next few years to come, in the commercial future of the world it must be recognized that cheap power will be the keynote of industrial advancement.

As statements from official sources, or as computed from all accessible sources of information, the amounts of water power available and developed and the horsepower per capita have been compiled and are here presented for the various industrial countries of Europe and America.

Water Power Available and Developed and Horsepower Per Capita for Various Industrial Countries of Europe and America.

Country	Area Square Miles	Population (Latest available figures)	Horsepower Available (1915 estimate)	Horse-power Developed (1915 estimate)	Per Cent Utilized	Horsepower Per Square Mile of Area		Horsepower Per Capita	
						Available	Developed	Available	Developed
United States	3,026,600*	92,019,900	28,100,000	7,000,000	24.9	9.3	2.31	0.31	0.076
Canada A	2,000,000	8,033,500†	17,820,000	1,712,193	9.6	8.91	0.86	2.22	0.21
Populated B	927,800	8,000,000	8,094,000	1,700,000	21.0	8.74	1.83	1.01	0.21
Austria-Hungary	241,330	49,418,600	6,460,000	566,000	8.8	26.8	2.34	0.13	0.011
France	207,100	39,601,500	5,587,000	650,000	11.6	27.0	3.14	0.14	0.016
Norway	124,130	2,302,700	5,500,000	1,120,000	20.4	44.3	9.02	2.39	0.487
Spain	194,700	18,618,100	5,000,000	440,000	8.8	25.7	2.27	0.27	0.024
Sweden	172,900	5,521,900	4,500,000	704,500	15.6	26.0	4.08	0.81	0.127
Italy	91,280	28,601,600	4,000,000	976,300	24.4	43.8	10.7	0.14	0.034
Switzerland	15,976	3,742,000	2,000,000	511,000	25.5	125.2	32.0	0.53	0.137
Germany	208,800	64,903,400	1,425,000	618,100	43.4	6.8	2.96	0.02	0.010
Great Britain	88,120	38,802,500	963,000	80,000	8.3	10.9	0.91	0.02	0.002

Canada "A", 2,000,000 square miles taken as the area treated in the Conservation Commission's Estimate of available water power, and the area which we may expect to see fairly thickly settled during the next few decades; 3,729,700 square miles = area of whole Dominion.

† 1911 Census + 12%.

* Excluding Alaska (area about half million square miles).

The comparison of the above figures is shown diagrammatically in Figure No. 1.

No uniform method of obtaining the figures of horsepower available has been employed; information as to the extent of possible storage, in the respective cases, not being available and, further, these amounts may be the aggregate of individual estimates, as in the case of Canada,* or estimates of district totals, as in the case of United States;† both of the latter cases, moreover, do not include maximum economic storage and include only such power plants as may reasonably be included within the range of market in the near future.

Notwithstanding such possible discrepancies in the compilation of available power, the developed power has permitted of close totaling, and thus, with population,‡ gives reliable figures for the horsepower per capita.

While the United States leads in available capacity and in power developed, and Norway leads in power developed per capita, available power in Canada is enormous, and the developed power now ranks second in amount developed and in amount per capita. The distribution of available power in Canada adjacent to the natural resources and to the transportation routes ensures the continuation of rapid development, there existing every indication that the rate set between 1911 and 1914, of an increase from 1,016,521 horsepower developed, to 1,712,193 horsepower developed, will be readily maintained.

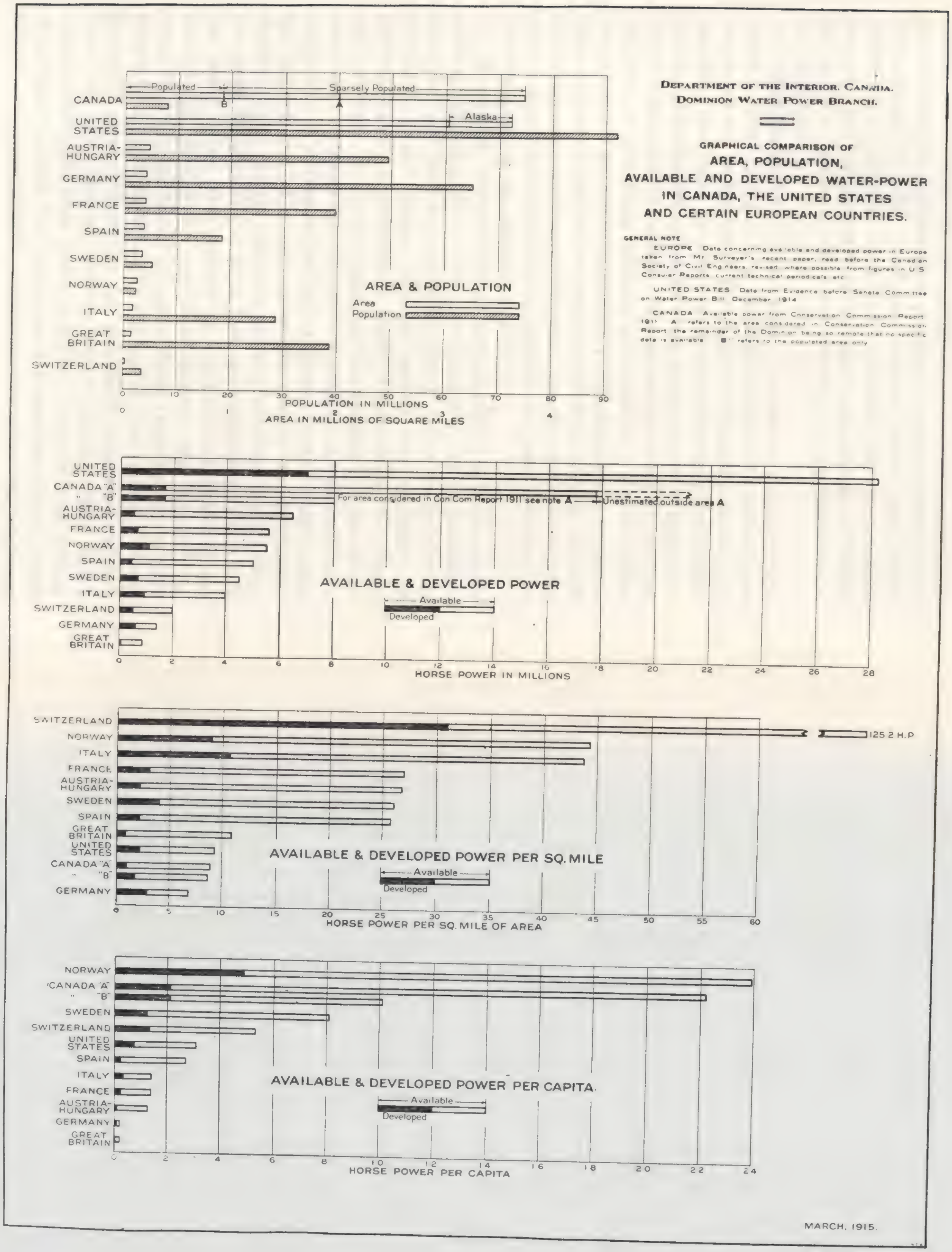
Twenty years ago, the position of the various manufacturing countries, in the scale of industrial production, undoubtedly bore a direct relation to the consumption of coal, and power was a major factor in industry. In the present day, where so many factors are in a transitional stage, it cannot be said that either coal consumption, alone, or water power developed, alone, is indicative of commercial standing, although the aggregate power equivalent may be so. All such studies of power economies, however, will disclose that low-cost power is the underlying element of the industrial world.

Fortunate as is Canada in water power distribution, the added advantage of a great share in the world's mineral re-

* "Water Powers of Canada", Commission of Conservation, Ottawa, 1911.

† Forest Service, Department of Agriculture, United States.

‡ Population compiled from Encyclopaedia Brittanica, 11th Edition.



DEPARTMENT OF THE INTERIOR, CANADA.
DOMINION WATER POWER BRANCH.
GRAPHICAL COMPARISON OF
AREA, POPULATION,
AVAILABLE AND DEVELOPED WATER-POWER
IN CANADA, THE UNITED STATES
AND CERTAIN EUROPEAN COUNTRIES.
GENERAL NOTE
EUROPE. Data concerning available and developed power in Europe taken from Mr. Surveyer's recent paper, read before the Canadian Society of Civil Engineers, revised where possible from figures in U.S. Consular Reports, current technical periodicals, etc.
UNITED STATES. Data from Evidence before Senate Committee on Water Power Bill, December, 1914.
CANADA. Available power from Conservation Commission Report 1911. "A" refers to the area considered in Conservation Commission Report, the remainder of the Dominion being so remote that no specific data is available. "B" refers to the populated area only.
AREA & POPULATION
Area
Population
Populated
Sparsely Populated
B
A
Alaska
CANADA
UNITED STATES
AUSTRIA-HUNGARY
GERMANY
FRANCE
SPAIN
SWEDEN
NORWAY
ITALY
GREAT BRITAIN
SWITZERLAND
POPULATION IN MILLIONS
AREA IN MILLIONS OF SQUARE MILES
AVAILABLE & DEVELOPED POWER
Available
Developed
UNITED STATES
CANADA "A"
" "B"
AUSTRIA-HUNGARY
FRANCE
NORWAY
SPAIN
SWEDEN
ITALY
SWITZERLAND
GERMANY
GREAT BRITAIN
For area considered in Con. Com. Report 1911 see note A
Unestimated outside area A
HORSE POWER IN MILLIONS
AVAILABLE & DEVELOPED POWER PER SQ. MILE
Available
Developed
SWITZERLAND
NORWAY
ITALY
FRANCE
AUSTRIA-HUNGARY
SWEDEN
SPAIN
GREAT BRITAIN
UNITED STATES
CANADA "A"
" "B"
GERMANY
125.2 H.P.
HORSE POWER PER SQ. MILE OF AREA
AVAILABLE & DEVELOPED POWER PER CAPITA
Available
Developed
NORWAY
CANADA "A"
" "B"
SWEDEN
SWITZERLAND
UNITED STATES
SPAIN
ITALY
FRANCE
AUSTRIA-HUNGARY
GERMANY
GREAT BRITAIN
HORSE POWER PER CAPITA
MARCH, 1915.

Fig. 1.

sources, with, moreover, the proximity of power to the mines, will by their interdependence provide a great stimulus to the development of both. Coal, iron, copper, nickel, gold, silver, cobalt, lead, asbestos, mica and corundum are the principal minerals, and the output value of these, aggregating $186,802,-406, in 1910, is one of the chief elements in the commerce of the Dominion.

The appreciation of low cost of power is relative only; relative, in the first place, to our ideas of absolute cost of commercial power as produced, possibly, by the steam engine, and secondly, when cost of power as a major factor in production is lower than the critical power cost at which manufacture becomes commercially feasible. We are apt to think of low cost of power as something tangible and absolute. Under certain conditions, steam power at $100.00 per horsepower per year is low-cost power, and under certain conditions, power at $6.00 per horsepower per year is high-cost power; $6.00 power may show a loss in an extensive electrochemical plant, while $5.00 power may show an attractive profit.

In general, low-cost power is considered by the majority to be synonymous with hydro-electric power. The constituents of power cost may be readily analysed. In a hydro-electric generating plant, charges against capital—the aggregate of interest, sinking fund to retire bonds, depreciation fund, taxes and insurance, etc.—go to make up the greatest portion of the total cost; water charge (if any), operation, maintenance and supplies, are, in general, the minor items. In the steam plant, the cost of fuel alone will generally greatly exceed capital charges, while capital cost of a steam plant may readily compare with the capital cost of an hydraulic generating plant. In the steam plant, the greater the capital cost properly expended, the greater the over-all efficiency; and thus the increase in the minor factor of capital charge may provide a more than proportionate decrease in the major item of fuel. In the hydraulic plant, efficiencies are practically standardized and fixed; capital charges, however, vary greatly, from many causes, within the wide limits of a low-cost plant with a head of several hundred feet, with small headworks and a small number of large capacity generating units, to the high-cost

plant with low head, with extensive construction and a multitude of small units.

Quality of power is an element in the cost of an hydroelectric plant. In the supply of industrial power, continuity of service and more or less adherence to a definite standard of electrical characteristics of the supply are the essentials of quality. Absolute continuity is impractical, and the safeguards required in securing even an approximation of continuity in generating plants and transmission and distribution systems are usually so costly as to prohibit cheap power. The electrical characteristics of voltage and frequency, as representing the factors of greatest appeal to the consumer, are dependent on design and operation, and their maintenance is readily to be obtained.

In the electrochemical and electrometallurgical field, the lowest cost power, only, can be entertained, and such is available only from the largest of plants; power at from \$6.00 to \$10.00 per horsepower per year must be the aim, to secure such a market.

While abundance of water powers exist in Canada, today only the most cautious governmental administration policies can provide for the anticipated requirements of the future. The majority of water powers within market range will undoubtedly be developed, and the future is one of vital importance.

It has been fortunate that, in Canada, the water power rights have mostly remained under the control of the Dominion or Provincial Governments. The Dominion Government controls navigable streams, and their water powers, throughout the Dominion and the water powers of the Provinces of Manitoba, Saskatchewan and Alberta; the Yukon and the Northwest Territories, Quebec and New Brunswick have granted powers, heretofore, on broad leases, while Nova Scotia has many of its water powers privately owned outright from eighteenth century Government land grants; these provinces are now planning much more efficient control. In the Province of Ontario, the administration has become of such exceptional nature that it is worthy of a very complete study, as being, possibly, the greatest of municipal power undertakings.

The Dominion Government's administration policy affords

every reasonable protection to the public, as to rentals, periodic revisions, control of rates, limited grants, etc., and, at the same time, fosters legitimate private enterprise to return reasonable profits. Regulations are in force affording all possible assistance to the development of water powers which have every reasonable assurance of economic utilization, and, further, before the authorization to proceed with development is given, complete investigations are undertaken to prove the economic features of design, capacities and costs, and, eventually, supervision is carried out during construction. Proper government supervision and control of the construction and maintenance of all developments is the only safe method of intelligently initiating construction and maintaining an adequate system of river improvement for power purposes.

The Hydro-Electric Commission of Ontario has created a world-wide interest as an experiment in publicly owned power. The history and results of the undertaking deserve fullest consideration in dealing with electric power in Canadian industry.

For some years previous to 1906, several of the energetic and leading citizens of central southwestern Ontario had endeavoured to secure a working basis for a comprehensive scheme of supplying power to the various municipalities, the City of Toronto comprising the largest interests in the matter. In 1906, the Provincial Government created a Commission empowered to investigate power conditions everywhere in the Province, and a further Commission was established after the rendering of the preliminary reports on the situation, which resulted in by-laws on the question of power supply being voted upon by the interested municipalities; and an agreement was entered into by the cities and towns of Toronto, Hamilton, London, Brantford, Guelph, Stratford, St. Thomas, Woodstock, Ingersoll, Berlin, Galt, Toronto Junction, Hespeler, St. Mary's, Preston, Paris, Waterloo, New Hamburg and Weston with the Hydro-Electric Power Commission of Ontario for a supply of electric power to be transmitted from Niagara Falls. The Commission is empowered, by Act of Parliament, to make expenditures for the carrying out of the necessary work, and these expenditures are repayable to the Commission by the municipal corporations which have entered into contracts. The price per

horsepower per year that each municipality has to pay for the respective block of power is the cost to the Commission and, in addition, (a) interest at the rate of 4 percent upon the moneys expended by the Commission on capital account in the construction or purchase of works; (b) an annual sum sufficient to form in thirty years a sinking fund for the retirement of the securities issued by the Province, under the Act, for the payment of the cost of the works; and (c) line loss and the cost of operating, maintaining, repairing, renewing and insuring the works. The amounts payable are annually adjusted and apportioned.

Tenders were called for the supply of electrical power from the producing companies at Niagara Falls, Ontario, and in March, 1908 the Commission entered into a contract with the Ontario Power Company for amounts up to 100,000 horsepower. Power was obtained from this source at the price of $9.40 per horsepower per annum for amounts up to 25,000 horsepower, and when the power demand exceeded 25,000 horsepower, the price became $9.00 per horsepower per annum. This price is for 12,000-volt, three-phase, 25-cycle power delivered in the Commission's transformer station at Niagara Falls.

In addition to the district served in the Niagara System, the Commission buys power from the Kaministiquia Power Company, of Fort William, Ontario, and sells to the City of Port Arthur; from the Ottawa and Hull Light and Power Company, selling to the City of Ottawa; from the Auburn Power Company, selling to the City of Peterborough; and from the York and Ontario Power Company for selling to the group of towns in the St. Lawrence System. Further, the Commission purchased the generating and distributing system of the Simcoe Railway & Power Company, at Big Chute, on the Severn River, and made considerable extensions to the distribution system, this plant being arranged to tie in with a generating plant being built by the Commission at Eugenia Falls, where a 542-foot head is to be obtained, and which is to supply power on June 1, 1915. A generating station and distribution system have just been completed at Wasdell's Falls, on the Severn River, at the outlet of Lake Couchiching, to supply power to the Wasdell's Falls system. The Commission is at present engaged on the

preliminaries to construction of radial electric railroads in the vicinity of Toronto and has undertaken the engineering and construction of the electrification works of the London and Port Stanley Railway.

A reference to the map (Figure 2) will well show the extent of the distribution area served by the Commission, excluding the Port Arthur, Ottawa and St. Lawrence systems. The transmission lines today aggregate 395.7 miles of double-circuit 110,000-volt line; 37 miles of single-circuit 110,000-volt line; 722 miles of single- and double-circuit pole lines of voltage from 13,200 up to 46,000; and 77 miles of low-voltage circuits. All the 110,000-volt lines, and the greater portion of the others, are included in the Niagara system.

On December 31, 1914, the number of customers served by the system was 96,744. On February 28, 1915, the power purchased by the Commission was over 100,000 horsepower.

Three features are outstanding: First, the power is intended to be available for every class of consumer, rural or urban; second, the equipment and general design are selected for most permanent and effective service; third, the power is supplied to the municipalities at cost.

Being assisted by complete, effective legislation from both Provincial and municipal standpoints, these operations of the Hydro-Electric Power Commission are the broadest examples of municipal ownership. The field entered by the Commission, wherever established municipal plants did not previously exist, was quite fully covered by private companies.

The adverse criticism which a publicly owned, electrical power system must expect when entering an established commercial market was based, at the inception of the Commission's plans, on the monopolistic tendency; on the possible effects of the introduction of Provincial party politics; and on the experimental nature of the scheme. The entire success as a commercial system, as an engineering work, and as a popular undertaking has entirely vindicated the situation.

The sale of power at cost eliminates much competition. This cannot be said to be creating a monopoly, as several of the established companies were able to reduce their rates to a corresponding amount, and with the decidedly less remunerative

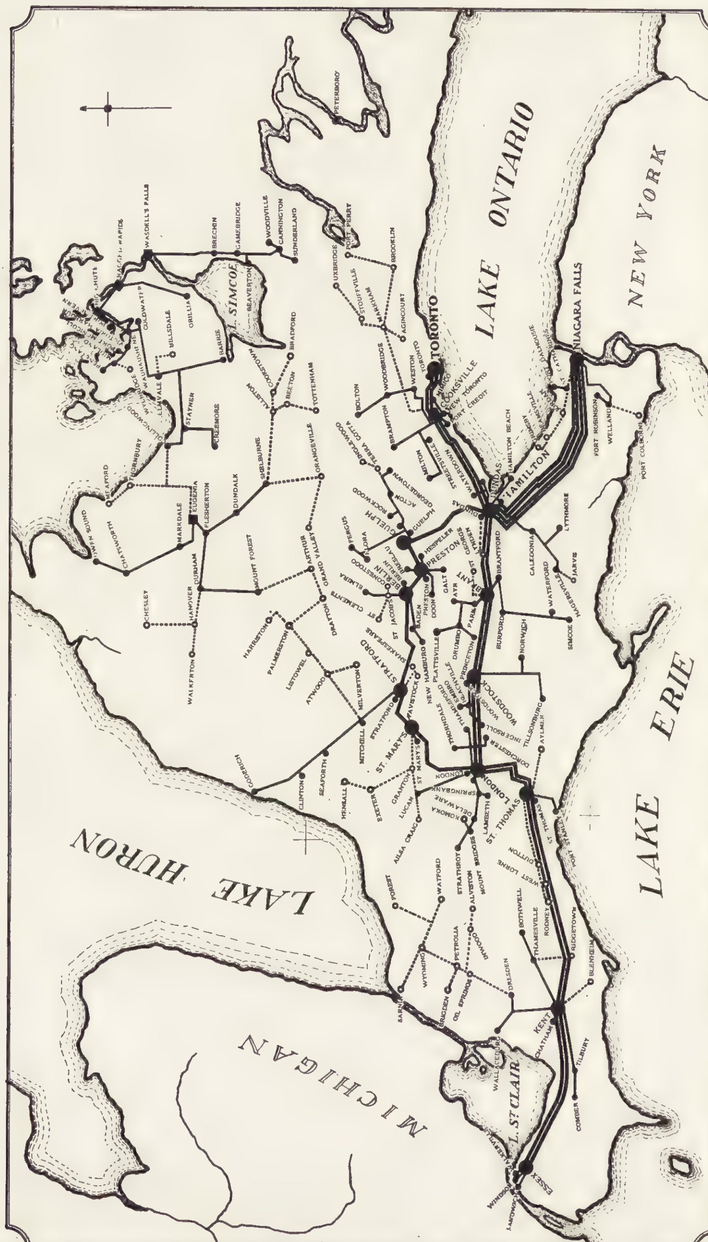


Fig. 2. Ontario Hydro-Electric Commission's Systems, Southwestern Ontario.

rates, have been able, by a much increased activity in the handling of business, to maintain a sound financial existence. The popular idea of the effect of a monopoly is that the public pays more and gets less in return, a condition certainly not comparable with the Commission's enterprise.

The selection of the personnel of the Commission has been a very judicious one, quite beyond criticism from the party standpoint, and to these men, of whom Sir Adam Beck, K. B., has been the chairman from the beginning, must belong much of the credit for the present position.

The experimental features of the engineering and commercial problems, involved, particularly, long distances, it being 233 miles from Niagara Falls to Windsor; the fact that 110,000-volt transmission at the time designs were commenced was in its earliest stages; that power was to be available to the municipalities at 25 cycles, for use in established markets using 60 cycles and 133 cycles; the necessary duplication in many cases of distribution systems; published power prices were based on estimates, only, of cost of construction and distribution; large blocks of power, with corresponding prices, were apportioned to the respective municipalities considerably in excess of their needs at the time, and in reality, in most cases, in excess of the power consumption from all sources of steam, water, gas and oil; an appreciably leavening factor was to be introduced into the industrial rivalry of the various communities; the consideration of an aggregate load of 100,000 horsepower, as was anticipated and which was to be an element in the ultimate success, was beyond the comprehension of the great majority; and possibly, lastly, no apparent provision was made for the development period in acquiring the load contracted for.

The analysis of the foregoing is quite beyond the capabilities of this paper. In 1908, the municipalities entering into the agreement subscribed for 29,335 horsepower; distribution of power was commenced in 1910; in 1915, the power will be in excess of 100,000 horsepower in the Niagara system alone. These figures may broadly suffice in place of a complete analysis, as each of the problems enumerated was eventually met by a successful solution. The rate of this growth in the Niagara system is shown in Figure 3, from 1910 to 1914.

The municipalities originally included in the power agreements numbered fifteen; on February 28, 1915, this number had increased to 82, and the growth in the number of consumers is well shown in the following table:

Approximate Number of Consumers (to December 31, 1914).

	1912	1913	1914
Light	33,568	63,157	93,179
Power	1,399	2,532	3,565
Total	34,967	65,689	96,744

The total cost of the Niagara System of the Commission to October 31, 1914, is as follows:

Transmission Lines		
Right-of-way	$ 574,806.67	
Steel Tower Lines	2,095,050.23	
Telephone	129,706.69	
Relay System Lines	54,537.32	
Conduit Systems, Ontario Power Co. to Niagara Station	66,844.67	$2,920,945.58
Windsor Extension (Operating 1915)		
Right-of-way	$195,060.87	
Steel Tower and Telephone Lines	835,734.97	$1,030,795.84
Duplication of Transmission Lines, Niagara to Dundas (Operating 1915)		
Right-of-way	47,264.25	
Steel Tower and Telephone Lines	258,305.92	$ 305,570.17
Wood Pole Line in operation	1,047,924.46	
Wood Pole Lines in course of construction	191,572.20	$1,239,496.66
Welland and St. Catharines District Lines		$ 8,239.20
Rural Line Construction		$ 159,382.23
Transformer Stations		
Stations in operation	1,905,352.25	
Stations and extensions in course of construction	342,080.83	$2,247,433.08
Distribution stations in operation	86,674.65	
Distribution stations in course of construction	5,138.18	$ 91,812.83
Total		$8,003,675.59

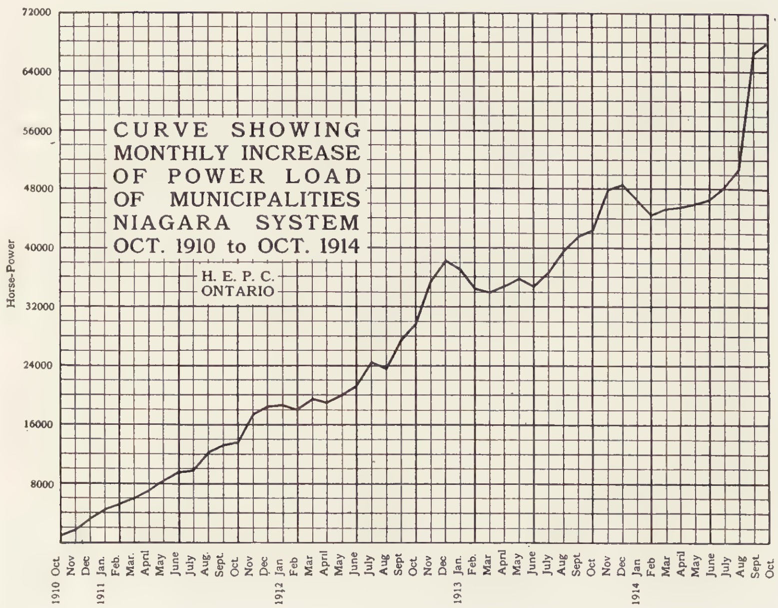


Fig. 3.

The aggregate of the annual cost of operation, capital charges, up-keep, etc., of the municipal systems is as follows, for the years 1912, 1913 and 1914:

	Dec. 31, 1912	Dec. 31, 1913	Dec. 31, 1914
Number of municipalities included in report	28	45	69
Operating and maintenance expenses	$1,086,135.00	$ 1,511,048.00	$ 2,012,754.07
Debenture charges and interest	291,033.00	479,995.00	661,949.23
Total annual expense	1,377,168.00	1,991,043.00	2,674,703.30
Total revenue	1,617,674.00	2,611,918.00	3,433,936.16
Gross surplus for year	240,506.00	620,875.00	759,232.86
Depreciation charge	179,847.00	230,480.00	357,883.31
Net balance, profits in excess of depreciation	60,659.00	390,395.00	401,349.55
Total plant value	6,349,711.00	9,196,483.00	12,901,125.43
Net debenture debt and overdraft	5,882,156.00	10,468,351.78	12,702,689.81
Accumulated gross receipts invested in plant extension		861,381.00	1,601,167.42
Accumulated depreciation reserve		410,327.00	850,618.07
Net surplus from operation		451,054.00	750,549.35

The assets of the 69 municipalities in the systems up to December 31, 1914, were:

Lands and buildings	$ 791,732.20
Sub-station equipment	1,476,087.84
Distribution system, overhead	3,422,763.93
" " underground	807,153.53
Line transformers	787,613.52
Meters	1,172,475.11
Street lighting equipment, regular	1,071,255.37
" " " ornamental	270,386.55
Miscellaneous equipment and construction equipment	2,062,035.90
Steam or hydraulic plant	420,108.33
Old plant	478,881.56
Other miscellaneous assets	140,631.56
	$12,901,125.40

The table in Figure 4 shows municipal power rates for the year 1914 and covers cost to municipality per horsepower per year, power rates, domestic and commercial lighting and street lighting.

The rates at which the Commission sells to the municipality consider the distance from the Niagara or other generating source, cost of 110,000-volt and 13,000-volt local systems of supply, and the amount and load factor of power consumed. The Commission recommends the rates to be applied by the municipality for the consumers, and the municipalities, in general, adopt them. The rates for sale are now on a uniform basis and involve a service charge, which, in case of power, consists of a flat rate of $1.00, a special rate of approximately 12 times the standard rate for the first fifty hours of service each month, and of approximately 8 times the standard rate for the second fifty hours of service each month, the balance being at a standard rate per kilowatt hour. Domestic lighting rates bear a service charge of 3 or 4 cents per 100 square feet of floor area per month, and a standard rate of from 2.5 to 7 cents per kilowatt hour. Commercial lighting rates, in general, have a service charge involving the first 30 hours per month, and a standard rate for all additional time. Discounts for prompt payment apply throughout. The average rate paid for domestic

1914

Municipality	Cost of Power to Municipality per h.p. per year	Lighting Rates: Domestic: Per 100 sq. ft.	Lighting Rates: Domestic: Per Kw-hr.	Lighting Rates: Commercial: 1st 30 hrs. per Kw-hr.	Lighting Rates: Commercial: All add'l per Kw-hr.	Lighting Rates: Prompt payment discount	Power Rates: Per h.p. per month	Power Rates: 1st 50 hrs. per month per Kw-hr.	Power Rates: 2nd 50 hrs. per month per Kw-hr.	Power Rates: All add'l per Kw-hr.	Power Rates: Prompt payment discount	Street Lighting
	$ c.	c.	c.	c.	c.	%	$ c.	c.	c.	c.	%	
Acton	36 00	4	5	10	5	10	1 00	4.3	2.9	0.4	10	$15.00 per 100 w. Incandescent
Ancaster	Served by Dundas	4	5	10	5	10	1 00	3	2	0.25	10	$14.00 " "
Baden	32 00	4	4.5	9	4.5	10	1 00	3.8	2.5	0.3	10	$12.00 " "
Barrie	33 70	4	4.5	9	4.5	10	1 00	3.6	2.4	0.3	10	$12.00 " "
Beachville	31 00	4	5	10	5	10	1 00	3	2	0.25	10	$10.00 " "
Beaverton	Note A	3	4	8	4	10	1 00	3.6	2.4	0.3	10	$13.00 " "
Berlin	21 50	4	3.5	7	3.5	25	1 00	2.1	1.4	0.2	10	$ 9.00 " "
Brampton	25 00	4	3	6	3	20	1 00	2.8	1.8	0.2	10	$ 8.00 " "
Brantford	19 50	4	3	6c. 1st 30 hr. 3c. next 70 hr.	0.15	10	1 00	1.9	1.3	0.15	10	$ 8.00 " " $40.00 Magnetite arc.
Bullock's Corn. and Greensville	Served by Dundas	4	4	8	4	10	1 00	2.8	1.8	0.25	10	$12.00 100 w. Incandescent
Caledonia	24 00	4	4	8	4	10	1 00	3.7	2.5	0.3	10	$12.00 100 w. "
Cannington	Note A	3	4	8	4	10	1 00	3.6	2.4	0.3	10	$13.00 " "
Chesterville	44 43	4	5	10	5	10	1 00	4.2	2.8	0.3	10	$13.00 " "
Clinton	41 00	4	5	10	5	10	1 00	4.9	3.3	0.4	10	$12.50 40 c.p. "
Coldwater	28 00	4	4	8	4	10	1 00	3.2	2.1	0.3	10	$12.00 100 w. "
Collingwood	33 97	4	4.5	9	4.5	10	1 00	3.6	2.4	0.3	10	$12.00 " "
Creemore	54 00	4	7	14	7	10	1 00	6.4	4.3	0.5	10	$12.50 " "
Dundas	15 00	4	3	6c. 1st 25 hr. 3c. next 75 hr.	0.15	10	1 00	1.6	1.1	0.15	15	$ 9.00 " "
Elmira	38 00	4	5	10	5	10	1 00	4.7	3.1	0.4	10	$12.00 " "
Elmvale	31 00	4	4.5	9	4.5	10	1 00	3.6	2.4	0.3	10	$12.00 " "
Elora	33 97	4	4.5	9	4.5	10	1 00	3.9	2.6	0.3	10	$12.50 " "
Fergus	33 97	4	4.5	9	4.5	10	1 00	3.9	2.6	0.3	10	$12.50 " "
Galt	21 50	3	2.5	6	2.5	10	1 00	1.9	1.3	0.15	25	$ 8.50 " "
Georgetown	36 00	4	5	10	5	10	1 00	4	2.7	0.3	10	$12.50 " "
Glen Williams	Served by Georget'n	4	6	12	6	10	1 00	4.3	2.9	0.4	10	$14.00 100 w. "
Goderich	37 00	4	4.5	9	4.5	10	1 00	4.8	3.2	0.4	10	$15.00 80 c.p. " $55.00 3 lt. standard $40.00 1 " $25.00 1 "
Guelph	21 00	4	4	8	4	25	1 00	2	1.5	0.2	25	$ 9.00 100 w. Incandescent
Hagersville	33 21	4	4.5	9	4.5	10	1 00	3.9	2.6	0.3	10	$12.00 " "
Hamilton	15 00	4	3	6c. 1st 25 hr. 3c. next 75 hr.	0.2	20	1 00	2.1	1.4	0.2	25 & 10	$ 8.00 " " $13.75 250 w. " $50.00 500 w. Nitrogen filled on standards
Hespeler	23 00	4	4.5	9	4.5	10	1 00	3	2	0.25	10	$12.00 100 w. Incandescent
Ingersoll	25 50	4	4	8	4	10	1 00	2.8	1.8	0.2	10	$12.00 80 w. " $12.50 100 w. "
London	23 00	4	3	6c. 1st 30 hr. 3c. next 70 hr.	0.6	25	1 00	2.5	1.7	0.2	10	$11.00 75 w. " $12.85 100 w. "
Midland	19 45	4	3	6	3	10	1 00	1.7	1.1	0.15	10	$13.50 " " $35.00 500 w. arc.
Milton	28 00	4	4	8	4	10	1 00	3	2	0.25	10	$ 9.00 100 w. "
Mimico	30 00	4	4	8	4	10	1 00	3.3	2.2	0.3	10	$11.00 " "
Mitchell	37 00	4	4	8	4	10	1 00	4.2	2.8	0.3	10	$12.00 " "
New Hamburg	32 00	4	4	8	4	10	1 00	3.8	2.5	0.3	10	$ 9.00 " "
New Toronto	28 00	4	4	8	4	10	1 00	3	2	0.25	10	$12.00 " "
Norwich	32 00	4	4	8	4	15	1 00	3	2	0.25	10	$12.00 " " $ 9.00 60 w. " $10.00 100 w. "
Ottawa	15 00	4	2.5	6	2.5	20	1 00	1.8	1.2	0.15	20	$45.00 Arc
Paris	21 00	4	3.5	7	3.5	10	1 00	2.5	1.7	0.2	10	$11.00 100 c.p. "
Penetang	26 50	4	3	6	3	10	1 00	1.7	1.1	0.15	10	$12.00 100 w. "
Peterboro	18 00	3	2.5	6	2.5	10	1 00	1.3	0.8	0.1	10 & 10	$12.00 16 and 32 c.p. " $50.00 500 w. arc. $50.50 Magnetite arc.
Petersburg and St. Agatha	Served by Baden	4	6	12	6	10	1 00	5.1	3.4	0.4	10	
Port Arthur	22 25	4	2.5	6	2.5	10	1 00	2	1.3	0.15	10	$ 5.00 60 w. " $ 8.30 100 w. "
Port Credit	28 00	4	4	8	4	10	1 00	3	2	0.25	10	$11.00 " "
Port Dalhousie	21 50	4	3	6	3	10	1 00	2.1	1.4	0.2	10	
Port Robinson	Served by Welland	4	3	6	3	10	1 00	1.8	1.2	0.15	10	
Port Stanley	42 70	4	4.5	9	4.5	10	1 00	5	3	0.4	10	$16.00 " "
Prescott	34 05	4	4	8	4	10	1 00	2.8	1.8	0.2	10	
Preston	21 00	4	4	8	4	20	1 00	2.3	1.6	0.2	20	$11.00 60 w. " $12.00 100 w. "
Rockwood	38 00	4	5.5	11	5.5	10	1 00	4.7	3.1	0.4	10	$13.00 " "
Seaforth	40 00	4	4	8	4	10	1 00	4.3	2.9	0.4	10	$15.00 " " $12.00 75 w. "
Sebringville	Served by Stratford	4	5	10	5	10	1 00	5.4	5.6	0.4	10	
St. Catharines	14 00	4	3	6c. 1st 30 hr. 3c. next 70 hr.	0.6	25	1 00	1.8	1.2	0.15	25	$ 8.00 100 w. "
St. Mary's	29 50	4	5	10	5	10	1 00	3.6	2.4	0.3	10	$13.00 100 w. " $25.00 250 w. Nitrogen $65.00 Arc
St. Thomas	28 00	4	2.5	6	2.5	20	1 00	2.5	1.7	0.2	10	$10.00 75 w. " $53.00 Arc
Stayner	43 57	4	4.5	9	4.5	10	1 00	4.2	2.8	0.3	10	$12.00 100 w. " $ 9.00 60 w. "
Stratford	30 00	4	4	8	4	20	1 00	3.6	2.4	0.3	10	
Sunderland	Note A	3	6	12	6	10	1 00	4.5	3.0	0.4	10	
Thamesford	45 00	4	6	12	6	10	1 00	5.6	3.8	0.5	10	$14.00 100 w. "
Thorndale	45 00	4	6	12	6	10	1 00	5.6	3.8	0.5	10	$14.00 " "
Tillsonburg	32 00	4	4	8	4	10	1 00	3.8	2.5	0.3	10	$11.00 " "
Toronto	15 00	4	3	8	3	10 to 20	1.35 1st 10 h.p. 1.00 all add'l	1.5	1	0.5	10 to 20	$ 9.00 " "
Walkerville	38 00	3	4	8c. 1st 30 hr. 4c. next 70 hr.	0.8	10	1 00	3.6	2.4	0.3	10	$10.50 60 w. "
Waterdown	26 00	4	5	10	5	10	1 00	3.5	2.4	0.3	10	$10.00 100 w. "
Waterloo	22 50	4	4	8	4	25	1 00	2.5	1.7	0.2	25	$ 8.75 100 w. mult. or 75 w. series Incandescent $10.00 100 w. series Incan. $10.50 150 w. mult. " $25.00 3 lt. standard, 1-100 w. and 2-60 w. $40.00 5 lt. standard, 1-100 w. and 4-60 w.
Welland	14 00	4	3	6	3	25	1 00	1.8	1.2	0.15	25	$18.00 250 w. Incandescent $ 9.00 100 w. "
West Hamilton	Served by Dundas	4	4	8	4	10	1 00	2.8	1.8	0.2	10	$14.00 " "
Weston	30 00	4	3	6	3	10	1 00	3	2	0.2	10	$12.00 " " $40.00 5 lt. stand., 4-100 w.
Winchester	43 77	4	4	8	4	10	1 00	3.1	2.0	0.25	10	$15.00 100 w. Incandescent
Windsor	38 00	3	4	8c. 1st 30 hr. 4c. next 70 hr.	0.8	10	1 00	3.6	2.4	0.3	10	
Woodbridge	33 83	4	4.5	9	4.5	10	1 00	3.9	2.6	0.3	10	
Woodstock	23 00	4	3	6	3	20	1 00	2	1.5	0.2	10	$25.00 250 w. $10.00 60 or 100 w.
Woodville	Note A	3	6	12	6	10	1 00	4.5	3.0	0.3	10	

Note A.—Service commenced during October, 1914.

Fig. 4. Ontario Hydro-Electric Power Commission, Power Rates, 1914.

service is calculated to be 3.7 cents per kilowatt hour. Street lighting rates are, in general, flat rates applied to the particular type of street lighting units used by each respective municipality.

Power is bought from the Ontario Power Company on a 20-minute peak basis and is taken by the municipalities in a similar manner. The oversale of power, by the Commission, resulting from the time distribution of the respective superimposing pay peaks is quite an appreciable amount, and is in excess of the line and transformer losses, etc., which has justified the Commission in excluding loss costs from power rates; the flattening of the load curve, however, over the 24-hour period is gradually reducing the oversale.

As examples of the nature of daily load curves, typical summer and winter loads are shown in Figure 5. The individual loads are typical commercial, domestic and municipal loads and do not include any electrochemical or electrometallurgical loads. The municipal nature of practically all the loads concerned has shown the possibilities of flattening the 24-hour load curve. Pumping to reservoirs is undertaken on off-peak hours and is responsible, to a great extent, for the magnitude of night loads, as shown; and again, the pumping equipment usually includes synchronous motors, which, when necessarily operating as day loads, have a power-factor corrective value favourably comparative with their energy consumption. The load factor on the Niagara system is said to average about 80%.

The Ontario Power Company, at Niagara Falls, the source of power for the Niagara system, has an installed capacity of 160,000 horsepower in 14 generator units, and, in addition to the Hydro-Electric Commission of Ontario, has a very large market established in New York State, through the Niagara, Lockport and Ontario Power Company, and a considerable market in Ontario adjacent to the generating plant*.

The big Chute generating station, owned by the Hydro-Electric Commission and which serves the Severn system, is shown in plan in Figure 6.

Previous to the use of the Commission's power, the industrial market for steam-generating central electric stations was

* See Publications issued by the Ontario Power Company.

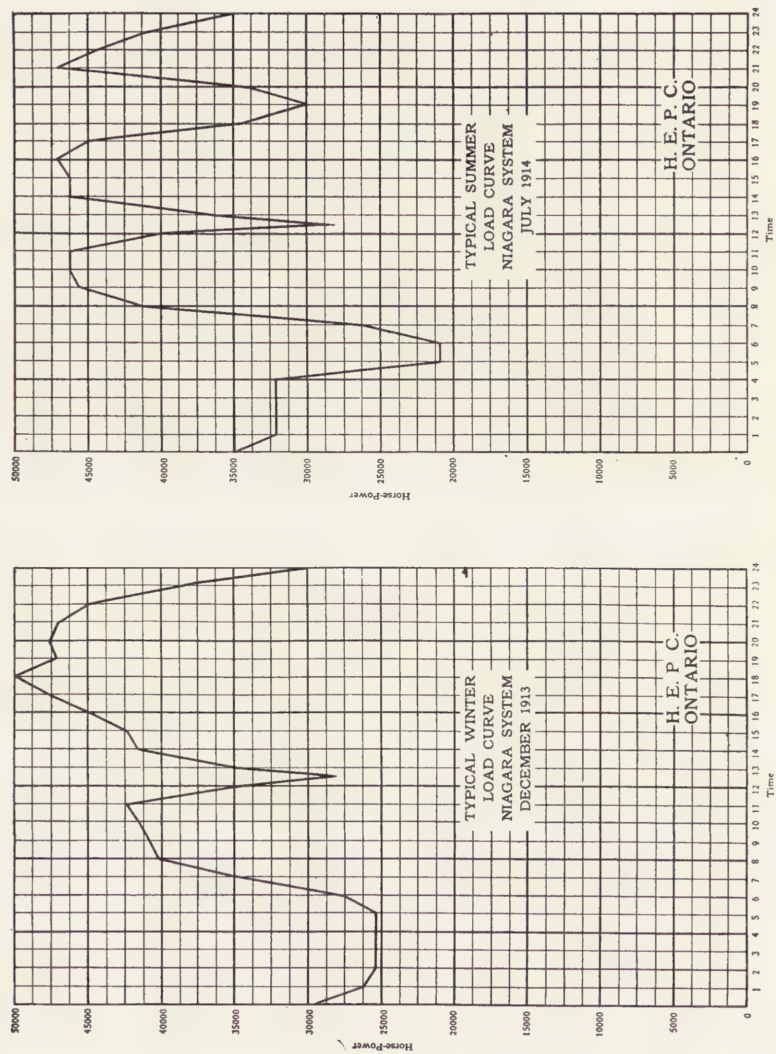


Fig. 5. Typical Winter and Summer Daily Load Curves.

DEPARTMENT OF THE INTERIOR, CANADA.
DOMINION WATER POWER BRANCH.

HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
PLAN, BIG CHUTE GENERATING STATION, SEVERN RIVER

To accompany paper "ELECTRIC POWER IN CANADIAN INDUSTRY"

INTERNATIONAL ENGINEERING CONGRESS
SAN FRANCISCO 1915

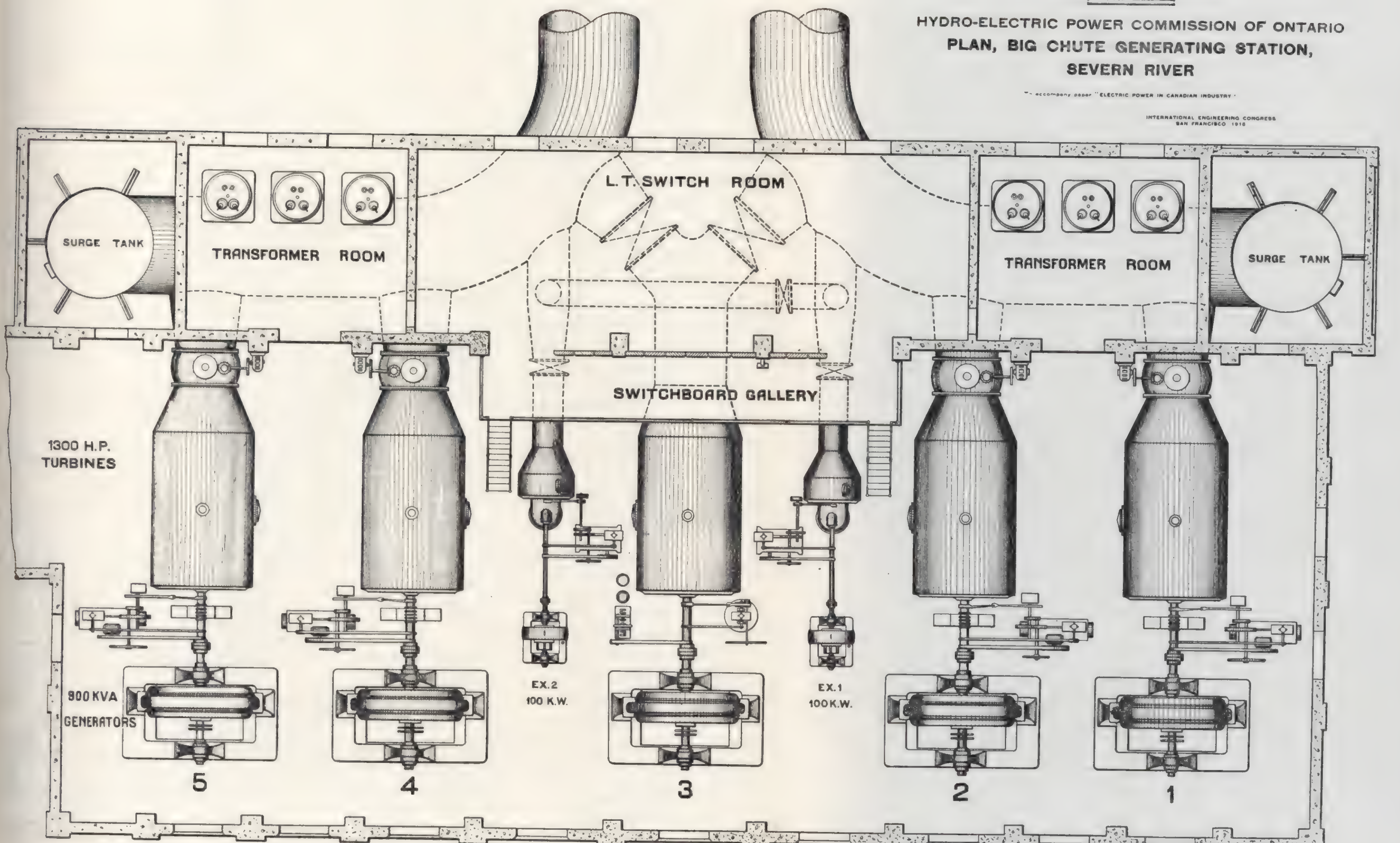


Fig. 6.

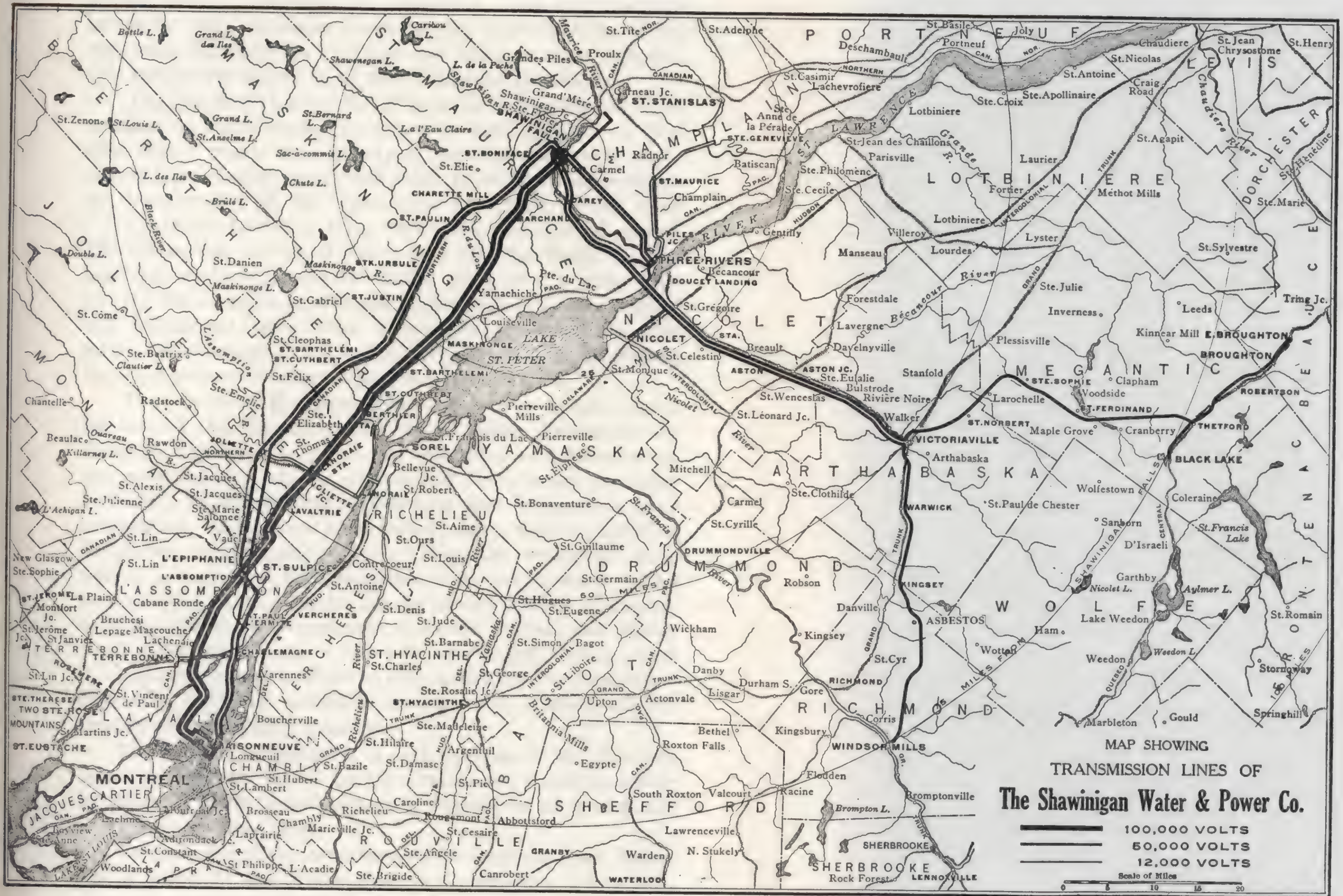

MAP SHOWING
TRANSMISSION LINES OF
The Shawinigan Water & Power Co.
100,000 VOLTS
50,000 VOLTS
12,000 VOLTS
Scale of Miles
0 5 10 15 20
PORTNEUF
LEVIS
DORCHESTER
CHAMPLAIN
LOTBINIERE
MEGANTIC
NICOLET
YAMASKA
ARTHABASKA
RICHELIEU
DRUMMOND
WOLFE
ST. HYACINTHE
BAGOT
RICHMOND
SHEFFORD
SHERBROOKE
ROUVILLE
CHAMBLY
LAVAL
JACQUES CARTIER
TERREBONNE
L'ASSOMPTION
MONTCALM
JOLIETTE
BERTHIER
MASKINONGE
ST. MAURICE
VERCHERES
ST. LAWRENCE RIVER
LAKE ST. PETER
SHAWINIGAN FALLS
THREE RIVERS
MONTREAL
MAISONNEUVE
SOREL
VICTORIAVILLE
SHERBROOKE
ST. STANISLAS
Grand'Mère
Grandes Piles
Shawinigan Jc.
Nicolet
Drummondville
Windsor Mills
Richmond
Asbestos
Thetford
Black Lake
Broughton
E. Broughton
Joliette
Berthier
St. Hyacinthe
Lachine
Longueuil

Fig. 7.

limited, as the rate for power from the water power companies bore a recognizable relation to cost of power from isolated steam power-plants of corresponding capacities. The municipalities served by the Commission represent the major portion of the industrial centres of the Province, and amongst these, considerable rivalry has existed as to their industrial growth.

The practice of granting of municipal bonuses—of fixed taxation or water rates, debenture or bond guarantees, free sites, money grants, etc., greatly in vogue several years ago—is gradually disappearing, and aside from these inducements the individuality of the community was chiefly based upon transportation facilities, labor economics and cost of power. The elimination of cost of power as a selective factor, by the application of comparatively similar rates over a wide area, and the discouragement of bonusing have led to a more fruitful and substantial competition among the municipalities; the active improvement of all public services directly influencing the conditions of transportation and labor.

The powers of the Commission are very wide and extend far beyond the distribution of power. Rates throughout the Province may be investigated and controlled on application of any municipality; existing systems and undeveloped sites may be bought or expropriated; systems, in part or complete, may be designed, financed and constructed; rivers may be improved for storage purposes, and so forth. These are particularly mentioned, as they have been included in the actual work of the Commission to date. Further, by its administration, conjointly with the Provincial Department of Lands, Forests and Mines, of all water-power matters under Provincial jurisdiction—that is, excluding only such affairs as arise under the Dominion Government's rights on navigable streams—the interests of the municipalities are fully guarded.

The existing competitors, in such portions of the Province as are not directly served by the Commission's system, either by influence of the Commission or by respect for its powers sell at quite comparable rates.

As examples of two conditions of development quite different in aspect to the Hydro-Electric Commission, but which, also, are well worth study, reference is made herein to the

Shawinigan system, in the Province of Quebec, and to the developed and undeveloped sites on the Winnipeg River, in the Province of Manitoba. Special attention must be directed to the curves of the Hydro-Electric Commission, to the curves of the Shawinigan system, and to the loads in the City of Winnipeg, as denoting the rapid growth in power consumption. It is to be found that throughout the whole of Canada the loads of the power systems have been increased in a like manner. The consideration of such rates of increase as being applicable to the future, creates a most striking condition, and the development to meet such demands can only be supplied by the most careful utilization of water power sources.

The Shawinigan Water and Power Company, at Shawinigan Falls, Quebec, has an interesting system for study as to industrial use of electric power. This plant is noted for several reasons: First, its magnitude; second, its extent of distribution; third, its creation of an industrial centre from the power standpoint alone; and fourth, its supplying of power for several electro-chemical plants.

Shawinigan Falls is situated on the St. Maurice River, about 20 miles north of the St. Lawrence River and about 80 miles east of Montreal. The St. Maurice River, on completion of the storage works now under construction,* will have a capacity of 204,000 horsepower at the minimum flow period, which practically corresponds to the present capacity of the installed machinery at Shawinigan Falls. The water is used in the two electric generating stations of the Company, and, in addition, water is sold to the Northern Aluminum Company for use in their turbines and to the Belgo-Canadian Pulp and Paper Company. The Northern Aluminum Company uses water to generate 33,000 horsepower for use in their reduction furnaces; the direct-current generators are installed connected to the hydraulic turbines, the water rates being on the basis of direct-current output. In the Belgo-Canadian Pulp & Paper Company, 14,000 horsepower is delivered by turbines on the pulp grinders. In addition, the Canadian Carbide Company, at Shawinigan Falls, utilizes 12,000 horsepower, and a cotton fac-

* See "Canadian Hydraulic Power Development", Mechanical Section, International Engineering Congress, 1915.

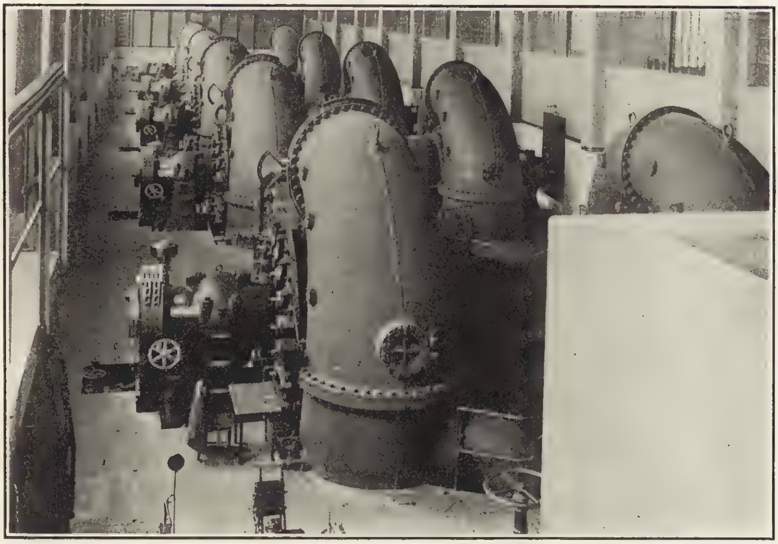


Fig. 8. Hydraulic Units, No. 2 Power Station, Shawinigan Falls, Quebec.

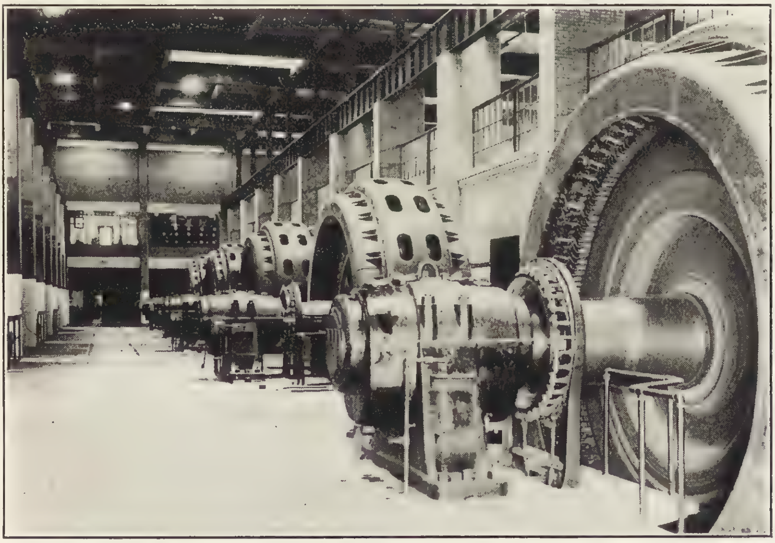


Fig. 9. Electrical Units, No. 2 Power Station, Shawinigan Falls, Quebec.

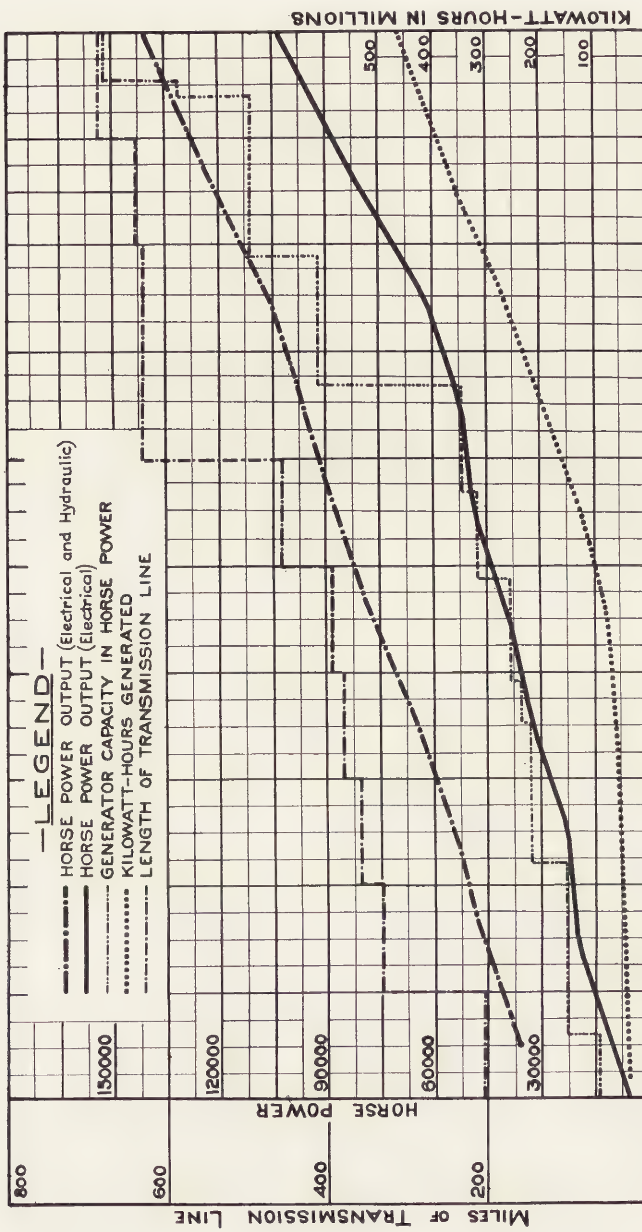


Fig. 10. Growth of Load and System, Shawinigan Water and Power Company, Shawinigan Falls, Quebec.

tory, 550 horsepower; so that, besides a miscellaneous local load, industries have been created, consuming nearly 60,000 horsepower, at a site where but a few years ago no community existed and transportation was entirely absent.

Figure 7 shows the large field which this Company serves with its 675 miles of high-voltage lines and 105,000 horsepower transmitted.

The Shawinigan Power Plants are two in number, aggregating approximately 150,000-horsepower capacity. No. 2 Plant* contains 5 units, each of 20,000-horsepower capacity. The hydraulic bay and electrical bay of No. 2 generating station are shown on Figures 8 and 9 respectively.

The greatest load of the power transmitted is at the City of Montreal, which is served with four transmission circuits, direct from Shawinigan Falls; this being but one source of the horsepower consumed in that city. A market for 6000 horsepower has been built up at the City of Three Rivers, on the St. Lawrence River, a location which affords excellent facilities for transcontinental railway service and lake and ocean transportation. The asbestos district in southern Quebec consumes several thousand horsepower, and the many municipalities in the various districts are also supplied.

The growth of power load and equipment of the Shawinigan Company affords an excellent example of the industrial growth of the country. Figure 10 shows the comparative values of generating capacity, length of transmission lines, horsepower output and kilowatt hours generated. Optimism as to the future of the industrial situation is indicated by the excess of generator capacity over the present load.

On the Winnipeg River, in Manitoba, two generating plants have been built to deliver power to the City of Winnipeg. The city itself has constructed a generating plant and transmission system, having a present capacity of 51,500 horsepower, at Point du Bois, 77 miles distant from Winnipeg, and the Winnipeg Street Railway Company has a plant of 28,200-horsepower capacity on the Pinawa Channel, near Lac du Bonnet. These plants have developed a large market in what is at present a non-manufacturing city (for other than local needs) of 210,000

* See "Electrical World", Vol. 59, p. 953.

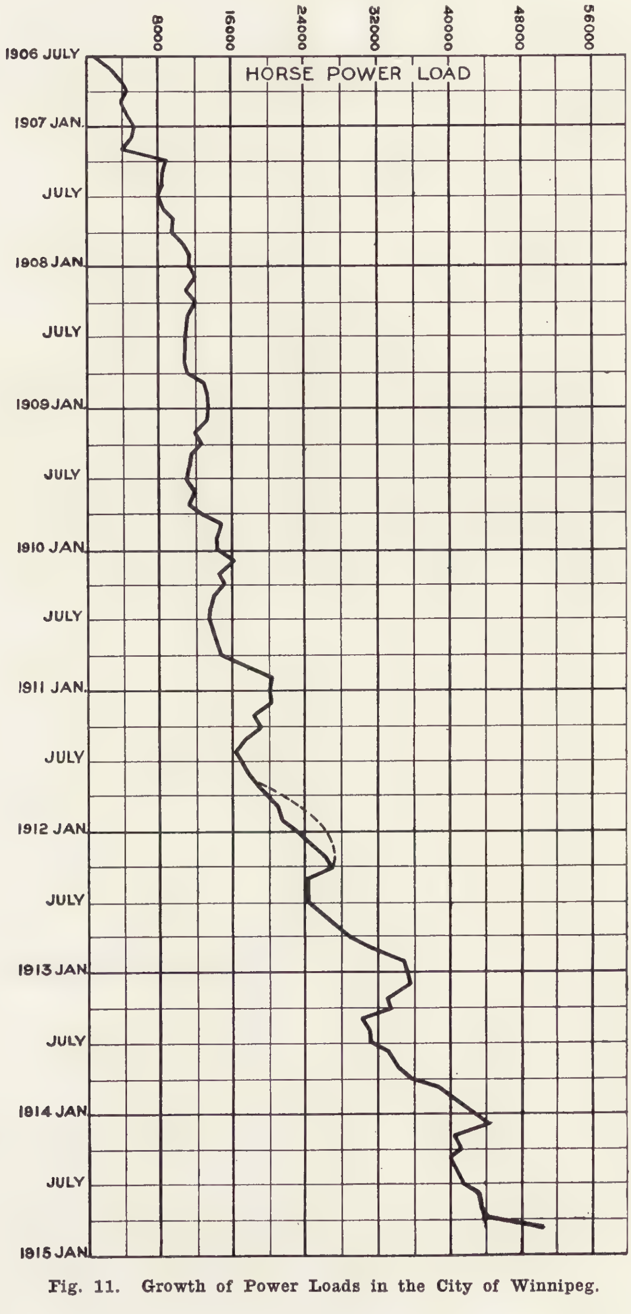


Fig. 11. Growth of Power Loads in the City of Winnipeg.

population. The magnitude and character of these loads may be realized from the curves shown in Figure 11, which shows the curve of growth of the combined loads from year to year.

On the Winnipeg River, within easy reach of three transcontinental railways and at the gateway to the agricultural West, is a series of power sites, which are being the subject of considerable study on the part of the Dominion Government as to the storage facilities and the economic possibilities in the development and market. Storage regulation is feasible to increase the minimum flow from 12,000 second-feet to 20,000 second-feet, which will result in several sites being well adapted for power purposes, the aggregate capacity of electrical power being 262,000 horsepower, in addition to 76,800 horsepower available at Point du Bois and 28,200 horsepower at the Winnipeg Electric Railway Company's site.

Western Canada is the granary for a world-wide market and the artificial replenishing of the notably fertile prairie soil is a problem for the future, to be solved only by abundant water supply. The communities, rapidly increasing in number and population, and the manufacturing now commencing for the local market will demand enormous quantities of power. The water powers must be developed for this purpose.

As companion curves to those included herein which show the growths in the loads of the Shawinigan Power Company, the Hydro-Electric Commission and the plants supplying the City of Winnipeg, the curves of the Calgary Power Company (Figure 12) and the British Columbia Electric Railway Company (Figure 13) are shown herewith. The latter companies serve the cities of Calgary and Vancouver respectively, the British Columbia Electric Railway Company representing but one of the hydro-electric systems supplying Vancouver.

In these curves, the record of the principal cities across a continent, it is remarkable that the growth of each has proceeded under such paralleling circumstances; truly this is the electrical age.

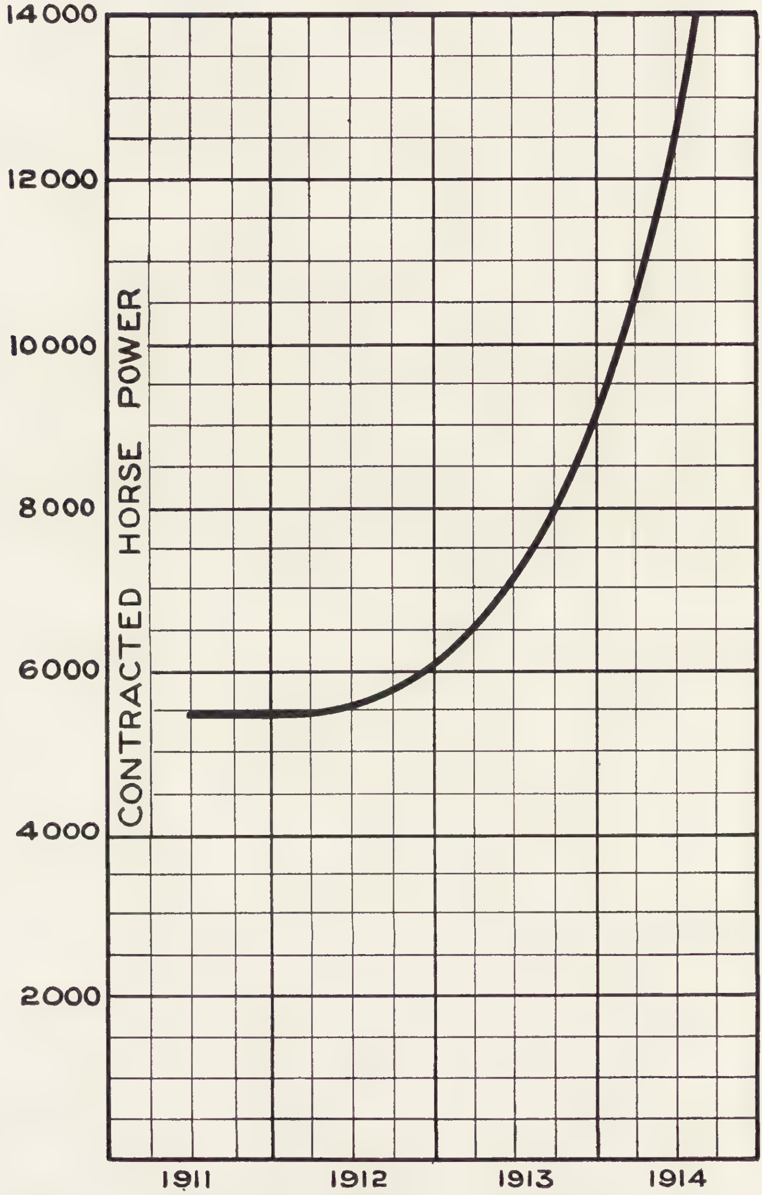


Fig. 12. Growth of Power Loads, Calgary Power Company, Calgary, Alberta.

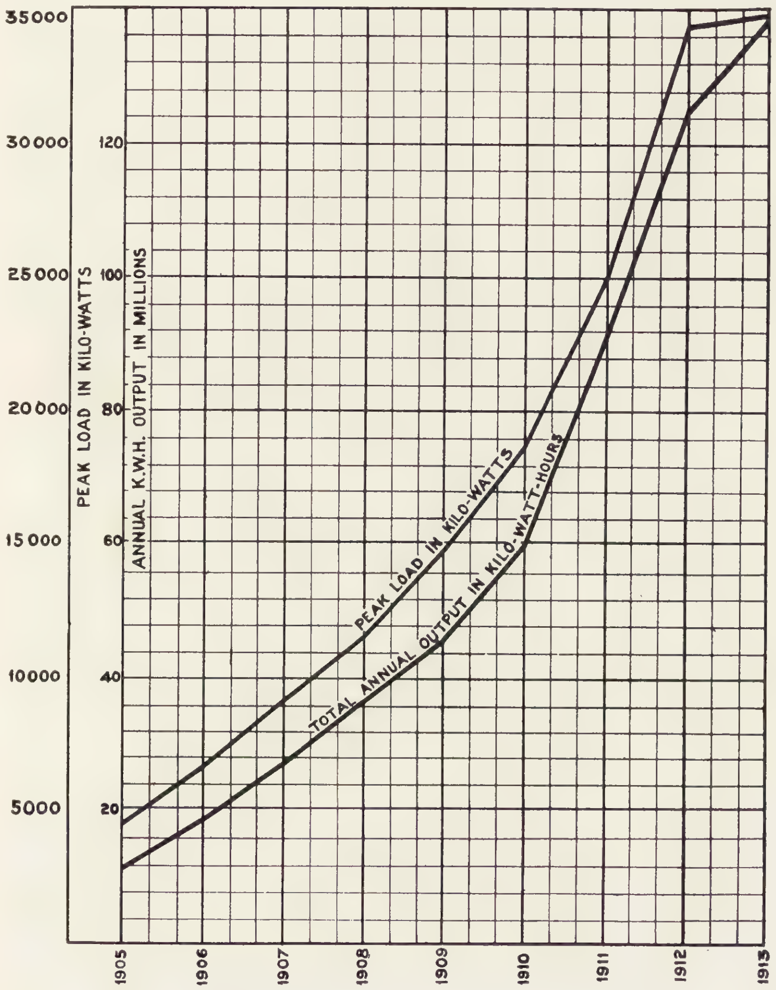


Fig. 13. Growth of Power Loads, British Columbia Elec. Rwy. Co., Vancouver, B. C.

DISCUSSION

Mr. Robinson. **Mr. L. T. Robinson,**† Fel. A. I. E. E., desired to ask if Fig. 5 was a load curve plotted from hourly readings.

Mr. Summerhayes. **Mr. H. R. Summerhayes,**** Assoc. A. I. E. E., wished to know just what items of cost are included in the rates.

Mr. Mitchell. **Mr. P. H. Mitchell,*** Assoc. A. I. E. E., replying for the author, said that curves were obtained from the graphic meter readings at Niagara Falls. From year to year the Commission makes reports embodying such typical curves as these. Regarding the rates, these include items A, B, and part of C but do not include the line loss. Oversale pays for the line loss. At present the load curves are flattening out in all municipalities due to various causes, for example, night pumping. In the future, line loss will have to be included in the rates.

† Engr., General Electric Co., Schenectady, N. Y.

** Ass't Engr., General Electric Co., Schenectady, N. Y.

* Consulting Engineer, Toronto, Ontario, Canada.

Paper No. 144

THE WATER POWER OF SWEDEN.

By

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The following article intends to describe the available water power of Sweden, and to what extent it has been put to use, and also the conditions under which water power can be utilized, specially in the northern part of Sweden, where undeveloped power still exists.

We are attaching separately brief descriptions of the more interesting technical features of Swedish water-power plants, and also some notes regarding legislation, governing authorities, and organizations that act on questions concerning development of water power.

AVAILABLE WATER POWER.

The total available water power in Sweden has, during the last few years, been the subject for calculations on several occasions.† The calculations have been based on fairly satisfactory records of observations and show that for a mean period of nine months of the year, power that is available and can be utilized in the whole country amounts to approximately 4.5 million turbine horsepower; of this, three fourths is north of Dalälfven. During the low-water period, the theoretical power available from the water-courses in present condition amounts to approximately one half of the above figure. The usual amount of installation

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* Translated by Carl J. Rhodin, M. Am. Soc. C. E.

† "Scandinavian Water Power and Its Future Prospects", Sven Lübeck, 1906.

"The Capital Value of the Water Power of Sweden", Mauritz Serrander, 1913.

up to this time has been 40 percent over the nine months' average; the total installation required would consequently amount to 6.3 million turbine horsepower for utilization of all the available water power.

Sweden is one of the most fortunate countries in Europe in regard to water power. It is about on a par with Norway, France, Italy and Austria.

By virtue of a great number of lakes, the run-off from the rivers in Sweden is relatively uniform in natural conditions and the freshets and torrents that are so common and troublesome in Alpine countries are practically entirely absent. The lakes also offer natural possibilities for effectual and relatively cheap regulation of the run-off. This regulation has taken place in a number of localities, and more is contemplated. On the most important water-courses, large lakes influence, on an average not less than 75 percent of the run-off, and the area of the lakes approximates 10 per cent of the drainage area. In addition to this, the large lakes are, as a rule, located on high plateaus, so that their regulating effect is of value for relatively long and important parts of the water-course. Lakes and water-courses have, as a rule, steep shores, and regulation, therefore, only seldom results in land damage of consequence. An estimate shows that if all the principal lakes of the country were regulated, an area smaller that 1/1000 part of the tillable soil would be submerged. On ten projects for regulation of large lakes, some of which have been carried out and some of which are contemplated, the total cost of storage is 0.2 öre ($0.00054) per cubic meter of water, and these lakes are 200 meters (656 ft.) above sea-level. Six other large lakes, in Norway, carry an expense for this item of 0.5 öre ($0.0013), but in this case the lakes are 650 meters (2132 ft.) above sea-level. The capital cost of storage per effective horsepower remains approximately the same, ordinarily fluctuating from 50 to 100 crowns ($13.50 to $27.00).

In this connection the extensive investigations of Mr. Axel Wallén should be mentioned. These have been carried out during the last year, and treat the periodical fluctuation of water levels and water quantities, and establish a possibility of calculation and prognostication for the future. It is evident that such

calculations are of great practical value for water-power development and for the industries that depend thereon.

DEVELOPED WATER POWER.

Since centuries, the great amount of available water power has been a most beneficial factor in the development of industries in Sweden; especially in connection with the utilization of the two principal natural resources of the country—the minerals and the forests.

As early as 1400, water power was developed for use in the famous manufacturing of iron. At the present time, this industry is located in the central part of the country. The next great development period commenced about 1870, in connection with the wood pulp industry, largely located in the southern and central parts of western Sweden, but also to an increasing extent in Norrland as far up as Luleå. The textile industries and the milling industries also utilize a considerable amount of water power.

The developments of the two last decades in power transmission and in electrochemical and electrometallurgical processes have also carried important advances with them. Nowadays, the southerly, the southwesterly and the central parts of the country are fairly well covered by electric distributing systems, that carry power principally from waterfalls for industrial and municipal purposes. These distributing systems belong largely to private corporations but some of them are owned by the state or by the municipalities. The principal distributing systems are the following, beginning from the south:

Hemsjö Kraft Aktie Bolag.

Sydsvenska Kraft Aktie Bolag.

Yngredsfors Kraft Aktie Bolag.

Trollhätte Works (Government owned).

Gullspångs Kraft Aktie Bolag.

Värmlands, Svartälfvens, Örebro, K. A. B., etc., in central Sweden.

Forsse Power Station, and the state-owned Älfkarleby Works and Porjus Works.

The total length of the more important transmission lines in Sweden is about 5000 km. (3107 mi.). Electric smelters, using

the method of the Electric Metal Company, are being operated at Domnarfvet and Hagfors and at Trollhättan, and are contemplated at several other steel works. Other electrochemical works have been built for the manufacture of carbide and carbide-nitrogen at Alby and Ljunga; also for the manufacture of silicon iron, manganese, etc., at Gullspång and at Vargön and Trollhättan, zinc at Trollhättan; and chlorates at Månsbo and Alby. Finally, this year, general electrification of railroads is being commenced by the installation of electric traction on the Kiruna Ore Line of the Government Railways, with power delivered from Porjus.

The following table shows the principal water-power installations:

Name	Owner	Turbine H.P. Installed	
Trollhättan	State	80,000	(110,000)
Älfkarleby	State	(52,000)	
Untra	City of Stockholm	(38,000)	
Porjus	State	37,500	
Bullerfors	St. Kopparbergs Bolag	30,000	
Laga Älf (4 works)	Sydsvenska K. A. B.	27,800	
Kvarnsveden	St. Kopparbergs Bolag	20,000	
Mockfjärd	Västerdalälfvens K. A. B.	20,000	
Gullspång	Gullspång-Munkfors K. A. B.	18,000	
Ljunga Werk	Stockholm Superphosphate A. B.	18,000	

Grouped according to size, the water-power plants in operation or under construction in 1915 are as follows:

Size	Number	Total Installation Turbine H.P.
50,000 H.P. and over	2	132,000
25-50,000 H.P.	3	108,000
10-25,000 H.P.	6	109,000
5-10,000 H.P.	18	116,000
1- 5,000 H.P.	128	253,000
200-1,000 H.P.	296	132,000
	453	850,000

The use of hydraulic power in 1915 is shown by the following tabulation. The amounts are approximate.

	Turbine H.P.	%
Iron industry	235,000	28
Timber and pulp industry	260,000	30
Textile industry	40,000	5
Electro-chemical industry	90,000	11
General power, etc.	225,000	26
	850,000	100

Power carried by distributing lines in 1915 amounts to a total of 415 thousand horsepower (this includes the State works); in the tabulation the largest consumers have been shown in their relative groups. The total utilized water power in 1915, including small installations, represents approximately 900 thousand turbine horsepower and can be said to correspond to approximately 15 percent of all available water power. Power developed at present from burning oil or coal, principally in steam-power developments, amounts to 400 thousand horsepower. About 60 percent of all installed water and steam power is transposed into electric power. About one half of the total annual value of products (estimated as 1,500 million crowns or $400,-000,000.00) of Swedish industry can be said to be created by means of water power as motive power. From this it may be seen that direct steam power usually is used for industries with less economic value.

Of the total energy produced in the country during 1913, 96 percent was utilized for major industries and only 4 percent for municipal and domestic usage, such as household use, on farms, and by railways (according to investigations by Mr. Axel Enström).

It should be noted that the domestic demand is usually to be found in the more compact communities. Domestic consumption outside of cities is only a fraction of one percent. It is of interest to note that of the 100 cities in Sweden, no less than 72 are now supplied or about to be supplied with hydro-electric power, and these water-power cities contain 90 percent of the total population in cities, and they also represent the same ratio in the value of products manufactured in cities.

It is apparent that only a small fraction of the available power in the northern part of the country has been utilized.

Upper Norrland utilizes only 3 percent; Lower Norrland utilizes only 16 percent, but South and Central Sweden utilize about 60 percent of the available water power. This is graphically shown on Plate I.

In Sweden the state owns about 16 percent of all available water power. This is principally located in Norrland, but also in the south of Sweden, namely, the whole fall distance in

Fig. 1. Bassalt Dam and Power House.

Götaälf between Lake Vänern and the sea, and some other waterfalls that have been purchased with a view of utilization in the future for electrification of the state railroads.

FUTURE ASPECTS OF WATER POWER DEVELOPMENT IN SWEDEN.

We are not going to discuss here utilization of electricity for domestic usage, that is, for light in the homes and for auxiliary machines for farming, or minor industries. These branches of use are, on account of high distributing cost and short time of usage, of a kind for which water power does not play any particularly important role. Electric heating and, still more, elec-

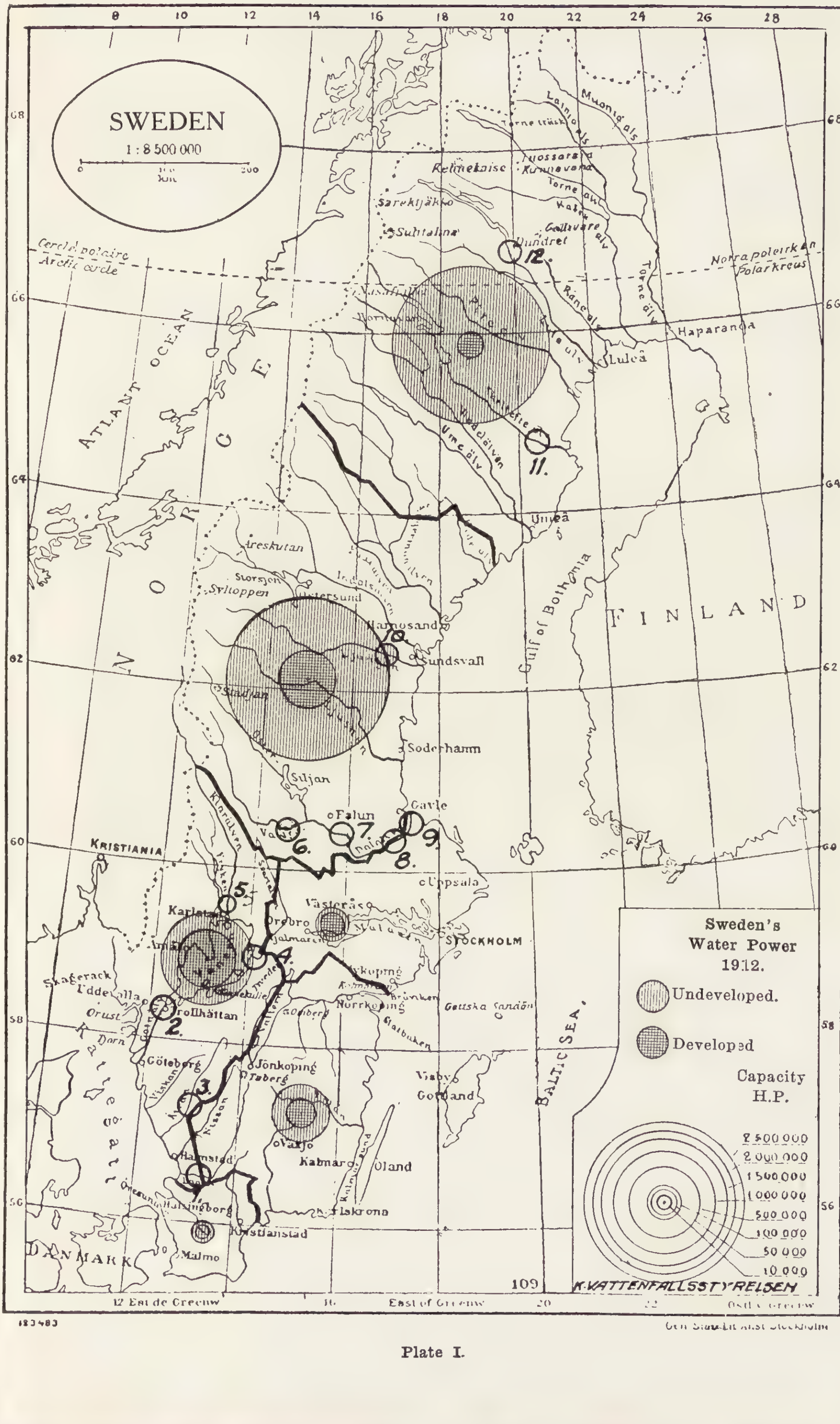
SWEDEN
1 : 8 500 000
Sweden's
Water Power
1912.
Undeveloped.
Developed
Capacity
H.P.
2 500 000
2 000 000
1 500 000
1 000 000
500 000
100 000
50 000
10 000
K.VATTENFALLSSTYRELSEN
ATLANT OCEAN
NORGE
FINLAND
Gulf of Bothnia
BALTIC SEA
Arctic circle
Cercle polaire
Norra polcirkeln
Polarkreis
Haparanda
Luleå
Umeå
Hernosand
Sundsvall
Soderhamn
Gavle
Falun
Uppsala
STOCKHOLM
Västerås
Örebro
Karlstad
KRISTIANIA
Trollhättan
Uddevalla
Göteborg
Jönkoping
Taberg
Norrkoping
Halmstad
Halsingborg
Kristianstad
Malmo
Karlskrona
Kalmar
Vaxjo
Oland
Gotland
DANMARK
Storsjon
Siljan
Sylltoppen
Areskutan
Dundret
Torne träsk
109

Plate I.

tric cooking, are very convenient; but especially electric heating is a very thankless economic problem. It has been shown that in order to heat up only the city of Stockholm with its 382,000 people, it would be necessary to gather together all available water power in the middle of the country and up to the Indal River—a total of one million horsepower.

It is however of interest to note that efforts are being made in the country districts to organize mutual power-using companies for distributing electric power, aiding in providing capital and establishing the possibility of getting power at a lower price. The economic importance of electric power for farming purposes is, however, being overestimated at the present time. Plowing by electricity is an unsolved problem that will never be of great importance in this country. For other farm uses, Alfred Ekström* considers that electric distribution is possible in localities where the tilled soil amounts to at least one third of the total, or where the density of the population amounts to at least 25 persons per square kilometer; this is the case only in a few territories in the south of Sweden. This is based on the assumption that the farmer can afford to pay an average price of 20 to 25 öre per kilowatt-hour, (5.4 to 6.8 cents).

Coming now to the use of electric power for the metal industries, we may here mention the beginning of use of electric motors in rolling mills. From a water-power point of view, the epoch-making developments are, however, to be expected within the electro-chemical, metallurgical and electrolytic industries, and specially within the field of electric furnaces. It is an important advantage to Sweden that electric smelting of charcoal iron has been technically solved and is economically profitable under favorable conditions. This is shown by the before-mentioned installation at Domnarfvet, which is now in operation, and other plants, and also by a number of proposed installations. By the method of electric smelting the shortage of charcoal is relieved for a long time to come. So far, no practical solution has been offered for smelting of iron with coke in an electric furnace. This does not, however, interest Sweden as much as

* "Electricity on the Farm", lecture before Royal Academie of Husbandry, Sept. 22, 1913.

the coal-producing countries; but for Norway, it would be of importance.

In order to find use in the future for a greater portion of the 3 or 4 million horsepower that are available in Norrland, we therefore depend first and foremost on the development of the steel and iron industry. This conclusion is warranted by the great supply of minerals in Central Sweden (Grängesberg, etc.) and in the Northerly Sweden (Gellivare, Kiruna, etc.). In both localities there are important water powers in the immediate vicinity of the ore fields. In the pulp and paper industry, no great expansion is to be expected of the pulp mills, but rather a development in the manufacture of a higher grade of product, by turning to paper production. However, the major quantities of power must find use in electro-chemical developments, not only in the manufacture of chlorides, carbide, cyanamide, iron alloys and zinc, but also in the manufacturing of nitrates, nitric acid, alkalies, aluminum, etc.

What are then the chances of a realization of these possibilities for the northerly water powers in Sweden? Cost of power and transportation are prime factors for all major industries. Additional factors of importance are import duties and trade relations. Here, a small country with limited consumption possibilities may easily have great difficulties. Finally, the location of the industrial center is of importance, inasmuch as the climate and the situation affect the well-being of the employees and the availability of help, and the demand for high wages.

The power cost from the better Swedish water-power projects is, as a rule, not any higher than the cost that must be carried elsewhere in the world. The transportation problem is, however, most important. Transportation affects raw materials first, and secondly, it affects the cost of transportation of the finished product. It is consequently evident that the problem may essentially differ for a water-power industry using materials found within the country as against one using imported materials. The great electro-chemical water-power developments of North Sweden are and will remain international in this sense, that they are depending for the sale of their products on the markets

of the world; they are also generally dependent on foreign supply of certain portions of the raw materials.

Under these conditions, it is without doubt a handicap that the Norrland water powers have a confined situation between Norway in the west (with its favorably located water power) and a coast on the east where the harbors are locked by ice during five or six months of the year.

However, we are hoping that the Swedish water-power industry will develop on a large scale. Lately the methods of developing water power have been properly adjusted to existing difficulties through engineering enterprise (see Appendix 2); we have available important domestic raw materials, and we can command a pioneering, sturdy and hardy race of leaders and workmen. In addition to this, transportation facilities to the northern part of the country are continually being improved by means of new railways, by keeping the harbors open in winter by the use of icebreakers, etc.

Water power development has, since centuries, in its various forms, been altogether to the advantage of the country. It still has all the essentials of importance in our economic future. The water-power plants, with their distributing systems and their utilizing industries, yield profit in many ways to the economic benefit of the community. They are important taxpayers to State and municipality. They produce freight for domestic and foreign channels of commerce and they offer new fields of labor for the people—an offset against emigration. Such communities as Domnarfvet, Avesta, Bergvik, Ljusne, Alby and Ljunga primarily depend on water-power industries. They are important centers and have development possibilities as long as the industrial works on which they depend can grow and develop without restriction.

Last but not least, the water-power industry is the one and only source that can give large economic development to northern Sweden. It is generally conceded that it is very important to improve the economy of the Norrland farmer by increasing his possibilities of marketing his products, etc.; but it is frequently overlooked that a flourishing industrial development is the only permanent consumer that can be counted upon.

APPENDIX No. 1.

A DESCRIPTION OF SOME LARGE WATER POWER PLANTS IN SWEDEN.*

No. 1, Sydsvenska Kraft A. B. (South Swedish Power Corporation).

This company at present owns and operates four power stations—Majenfors, Bassalt, Öfre Knäred and Nedre Knäred—on the River Lagan. All the plants have, by a chance, the same hydraulic head, about 10 meters (32.8 ft.); they are located

Fig. 2. Öfre Knäred Dam and Power House.

along a stretch of cascades 9½ kilometers (5.9 mi.) in length. The four plants develop power for transmission to the cities of Malmö, Lund, Landskrona, Helsingborg, Halmstad, etc., who own the enterprise.

The power plant at Öfre Knäred is also a central station to which the power from the other stations is first conducted, and then distributed. By virtue of forebays of considerable size

* The detailed descriptions of the power plants which are here enumerated are to be found in the publications of the Water Falls Direction, the Water Power Association of Sweden and Vattenbyggnadsbyrån (The Hydraulic Engineering Bureau, Inc.). The location of each plant is shown on Plate I by a circle, with the number referred to in the text.

Translator's Note.—1 crown = 27 cents.

above the diversion dams, it is possible to practice great economy at low water time, using water to correspond with the consumption of power only.

The dams at Majenfors, Bassalt and Öfre Knäred are built largely of concrete on solid rock foundation. They have eight upper sluiceways, each with 4 meters (13.12 ft.) clear width and 3.2 meters (10.50 ft.) depth below high water. In addition to these openings, there are arrangements for fish ladders for the salmon and a ladder for young eels, and an opening for washing out ice. The main openings are closed by gates built of buckled plates 5 millimeters (0.196 in.) thick, on an iron frame. For operation of the gates, there is an electric hoist running on rails along the length of the dam. The openings for the gates can be closed in emergency by timber needles.

In the dams at Bassalt and Knäred there are in the bottom five openings 3 meters (9.84 ft.) wide and 2.2 meters (7.22 ft.) high, by which the water was diverted during construction. These openings were afterwards closed—three permanently and the other two by means of shutters which will permit emptying the dam for repairs or alterations. These shutters can be operated by means of the hoist for the main gates. Along the whole front of the dam and 300 millimeters (11.81 in.) from the edge, there is a drainage gallery consisting of 51 millimeters (2 in.) unglazed terra cotta pipe. These stand vertically on top of each other at a distance, center to center, of 600 millimeters (23.62 in.). The pipes reach from the top of the dam down to about ½ meter (1.64 ft.) from the bottom. For inspection of the drains, and also for inspection of the body of the dam, there is a tunnel 1.8 meters (5.91 ft.) high and 0.9 meter (2.95 ft.) wide, plastered with cement on the inside; into this tunnel drain the vertical pipes, and, also, 76 millimeter (3 in.) pipes, 2 meters (6.56 ft.) center to center, leading from the under body of the dam.

All four power stations are equipped alike with three turbines of 2000 hp., in open chambers of reinforced concrete. From Öfre Knäred the water is conducted by means of a diversion canal along the side of the river to Nedre Knäred.

The total cost of all four power stations, including purchase

of the water rights, has amounted to 5.8 million crowns ($1,-566,000). Constructing Engineers: Vattenbyggnadsbyrån (The Hydraulic Engineering Bureau, Inc.).

No. 2, Trollhättan.

This power development is the property of the State of Sweden and utilizes the Trollhättan Falls in Göta River.

The hydraulic head is about 30 meters (98.42 ft.) and the power developed is principally transmitted to the City of Gothenburg and other places. It is also used for electro-chemical industries in the vicinity of Trollhättan.

The water is diverted at the uppermost fall, where a submerged diversion dam has been built. The water is then conducted through a diversion canal about 1300 meters (4265 ft.) long, along the west shore of the river to a forebay where grizzlies and regulating gates are located. From the forebay the water is carried through tunnels blasted in solid rock and sheeted with iron plate to the turbines, which are placed in the power house itself. The power house is located on the shore of the so-called Olide Hole, into which the water is discharged after having passed the turbines. (See Plate II.)

The forebay is located on solid rock ledge; it has four gates, separated by piers of solid granite. The two central openings each have a free width of 20 meters (65.62 ft.) and are closed by rolling dams 3.6 meters (11.81 ft.) high. The first opening to the right, located along the side of the river, is 19.7 meters (64.6 ft.) wide and is closed by means of five shutters 3.7 meters (12.14 ft.) in width. The shutters are supported by the gang-way and by a footing in the foundation. They have frames of iron and covering of planks. They are split in two horizontally and can be either pulled up or pushed down. The last opening furthest to the left is 3 meters (9.84 ft.) wide and has a similarly constructed shutter. Both the rolling dams and the shutters can be operated either by electric power or by hand, and all openings can be shut temporarily by means of needles, constructed from steel pipe, that rest against a footing and the runway. To ensure operation during winter time, the rolling dams are provided with heating elements inside, by which the plate can be heated so that ice will not adhere.

The main inlet on the river has six openings with a free width of 12 meters (39.37 ft.), supported by granite piers. There is no discharge gate in the headworks. For protection against drift ice there is a timber ice fender securely anchored and provided with an apron 90 centimeters (35.43 in.) deep under the water surface. The inlet can be closed by means of movable shutters, 4 meters (13.12 ft.) wide, which are supported by heavy benches placed in shoes and resting against the runway. These shutters are operated by means of an electric hoist on wheels.

The inlet canal is partly blasted out in solid rock and partly built of stone masonry. About 350 meters (1148 ft.) below the inlet there is a Stoney gate 17 meters (55.77 ft.) wide and 9 meters (29.53 ft.) high, weighing approximately 60 tons. (See Fig. 3.) This gate is located at the place where a branch, in the future, will divert water to an increased development. On the lower portion of the inlet canal, for a distance of approximately 35 meters (115 ft.), the sides are vertical and are built of vitrified brick below the water surface and cut granite above the water surface. In this portion of the canal the rating for the efficiency tests of the turbines is made according to the diaphragm method devised by the late Prof. E. Anderson of the Technical University of Stockholm.* The canal walls are built of granite masonry when 6 to 7 meters (19.7 to 23 ft.) high, and of concrete, 1:5:7, for greater heights. Back of the water-proof surface are placed 51 millimeters (2 in.) terra cotta drainage tile, spaced on 0.5 meter (1.64 ft.) distance, connected by similar outlet pipes. In order to prevent the occurrence of temperature cracks, there are expansion joints of tongue-and-groove pattern packed with canvas in asphalt.

The turbine intake (see Fig. 4) directly connected to the forebay, is located on the brow of the mountain above the Olide Hole. In order to guard against water flowing over the power house, in case of closure of all or several turbines, the sides of the forebay are arranged as weirs, from which the water is led to the river. There is also a discharge opening for ice on each side of the turbine intake. Gates and grizzlies in front of the turbines are erected within a building of granite and concrete; each turbine

* For a detailed description of this method see: Weidner, Bulletin Univ. of Wisconsin, No. 672, 1914. (Translator.)

is supplied by means of a separate tube coming from a separate chamber that can be shut off either by a gate or by a movable

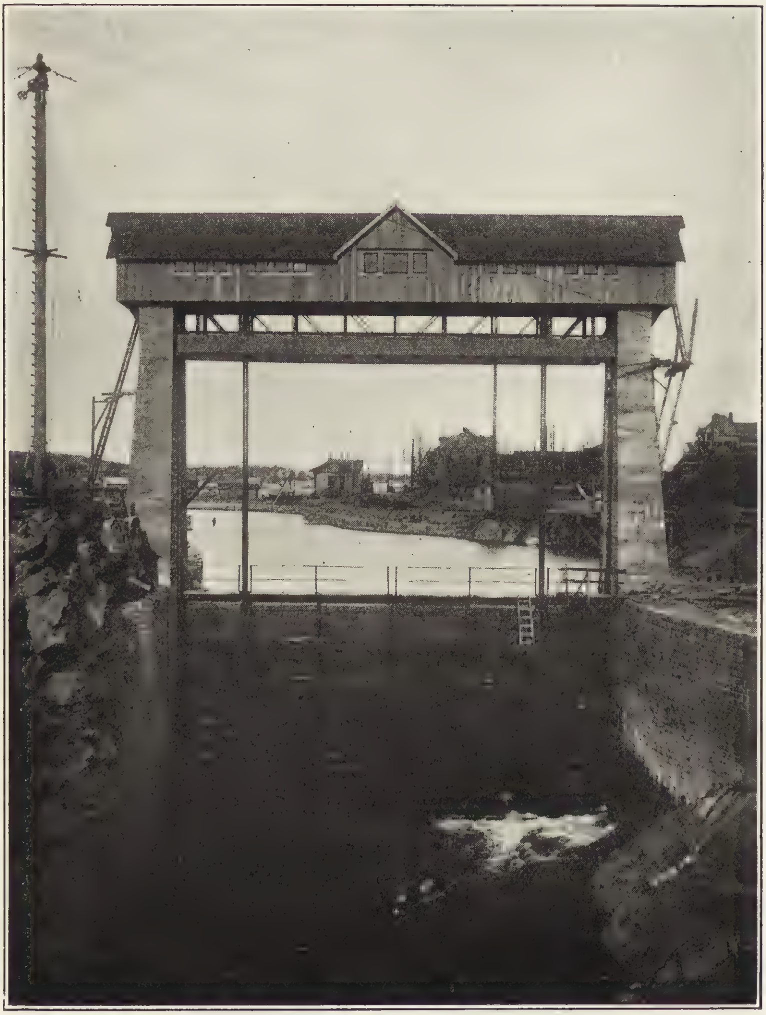

Fig. 3. Trollhättan Development. Stoney Gate in Inlet Canal.

shutter. The grizzlies are inside of the controlling gates and it is consequently possible to clear the intakes from obstructions independent of each other. In order to insure against clogging by

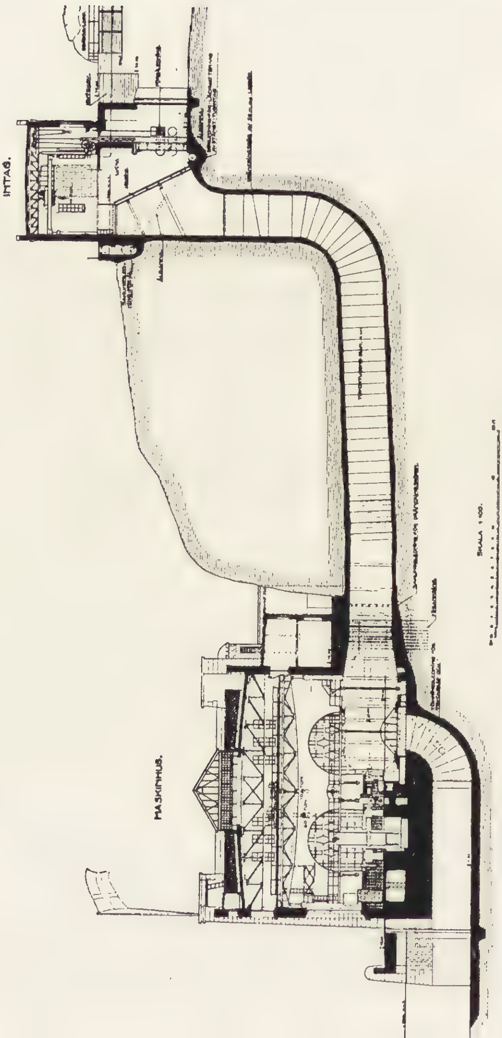

Fig. 4. Trollhättan Development.

needle ice, they are provided with arrangements for electric heating. Needle ice has at times caused interruption to service in an old development at this site. Each regulating gate has a width of 8 meters (26.25 ft.) and can be operated by means of an electric hoist or hand power.

There are 11 tubes: 8 large tubes with a diameter of 4.25 meters (13.94 ft.) and 3 smaller tubes 1.2 meters (3.94 ft.) in diameter. The latter convey water to the 3 exciting units. Each

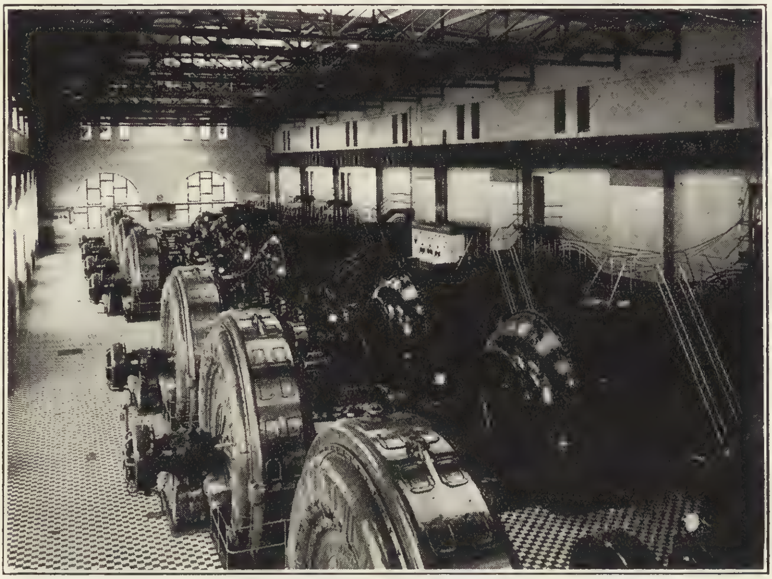

Fig. 5. Interior View of Trollhättan Power House.

tube, the length of which is about 60 meters (196.85 ft.) consists of a tunnel in solid rock sheeted with steel plate, backed by concrete.

The main power house (see Figs. 5 and 6) contains 8 twin turbines, each of 10,000 horsepower, directly connected to the generators. These are horizontal-shaft machines with enclosed sheet-iron cases. An extension containing 3 additional units is under construction at present. The power house itself is built of granite-faced brick. The gate house contains the transformers and the regulating gates, and also a central control room, a

repair shop, a laboratory, a room for meter testing, and an operating office. The building is a 3-story brick structure with basement.

The present installation of 80,000 horsepower has cost 11.5 million crowns ($3,105,000) and the transmission and distributing system has cost an additional 5 million crowns ($1,350,000). Constructor: Water Falls Direction.

No. 3, Haby.

This installation is located on a tributary of the river Viskan and belongs to the city of Borås. The power, developed from

Fig. 6. Power House, Trollhättan Development.

a 28-meter (91.86 ft.) head—about 5,500 horsepower—is principally used in the important textile manufactory of the city of Borås and its vicinity. The installation possesses unusually favorable regulating possibilities; regulation without waste can completely follow change of load.

The development consists of two regulating dams, the lower of which is an integral part of the power plant; also a short open canal and a steel pipe-line about 800 meters (2625 ft.) long, 4 meters (13.12 ft.) in diameter, with a pressure tower, diameter 15 meters (49.21 ft.), located on an adjacent height. The power

station has two units and a discharge canal. The construction of the pipe-line and its support on saddles is of special interest and is shown on Fig. 8. Construction cost for hydraulic development, 1.1 million crowns ($297,000); for machinery equipment, 260,000 crowns ($70,200).

Constructor: Vattenbyggnadsbyrån (The Hydraulic Engineering Bureau, Inc.).

No. 4, Gullspång.

This power plant is the property of the Gullspång-Munkfors Power Co. and is intended for general power distribution, and also for electro-chemical industry. The principal features of the installation are a dam in the Gullspång River, a supply canal about 150 meters (492 ft.) in length, power station, draft tube

Fig. 7. Haby Power House, Pipe Line and Pressure Tower.

and tail race; the hydraulic head is approximately 23 meters (75.46 ft.). On the west side of the river the diversion dam is a straight rock dam. On the other portion of the river, rock foundation is at great depth and it was decided to construct an arch dam of 40 meters (131.2 ft.) span, 6.5 meters (21.32 ft.) radius, and 3 meters (9.84 ft.) thickness of the arch. (See Figs. 9, 10 and 11.) The dam is built of concrete reinforced in the upper portion. The outlet openings are closed by wooden shutters divided into ten groups, supported by piers; each opening is 4.6 meters (15.09 ft.) wide and there are five gates for each opening. The dam has also a fish ladder and two eel ladders. A tun-

nel of 50 sq. meters (538.19 sq. ft.) area, 50 meters (164.04 ft.) in length, was used during construction to divert the water, and

Fig. 8. Saddles for Supporting Penstock, Haby Development.

this was later closed by a concrete arch built in the tunnel. The lower part of this arch was cast while submerged.

Fig. 9. Plan of Power Development on Gullspång River for Gullspång-Munkfors Power Co.

The powerhouse is intended to take six main units of 5000 horsepower and two exciter units. At present, four main units are installed.

The turbine chambers are built of reinforced concrete provided with expansion joints. At the lower end they are connected with vertical steel cylinders which are for the main units, 13 meters (42.65 ft.) deep and 5.5 meters (18.04 ft.) in diameter.

Fig. 10. Dam on Gullspång River.

Each chamber has in front a grizzly and buckle-plate regulating gates. The draft tubes from the turbines discharge into the tail-race which enters under the power house. The floor of the power house rests directly on rock foundation. The walls are separated from the turbine chambers in order to obviate dampness.

This development has cost approximately 3.5 million crowns ($945,000).

Constructor: Vattenbyggnadsbyrån (The Hydraulic Engineering Bureau, Inc.).

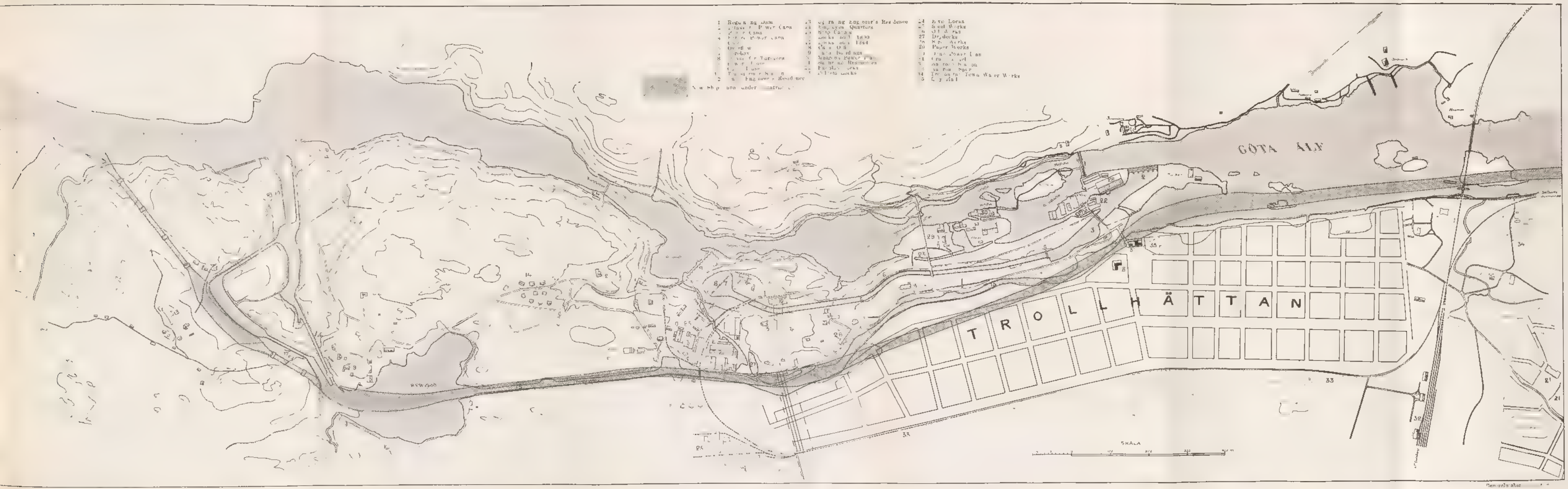

Plate II Plan of Trollhättan Power Development

Plate III. Plan of Untra Power Development.

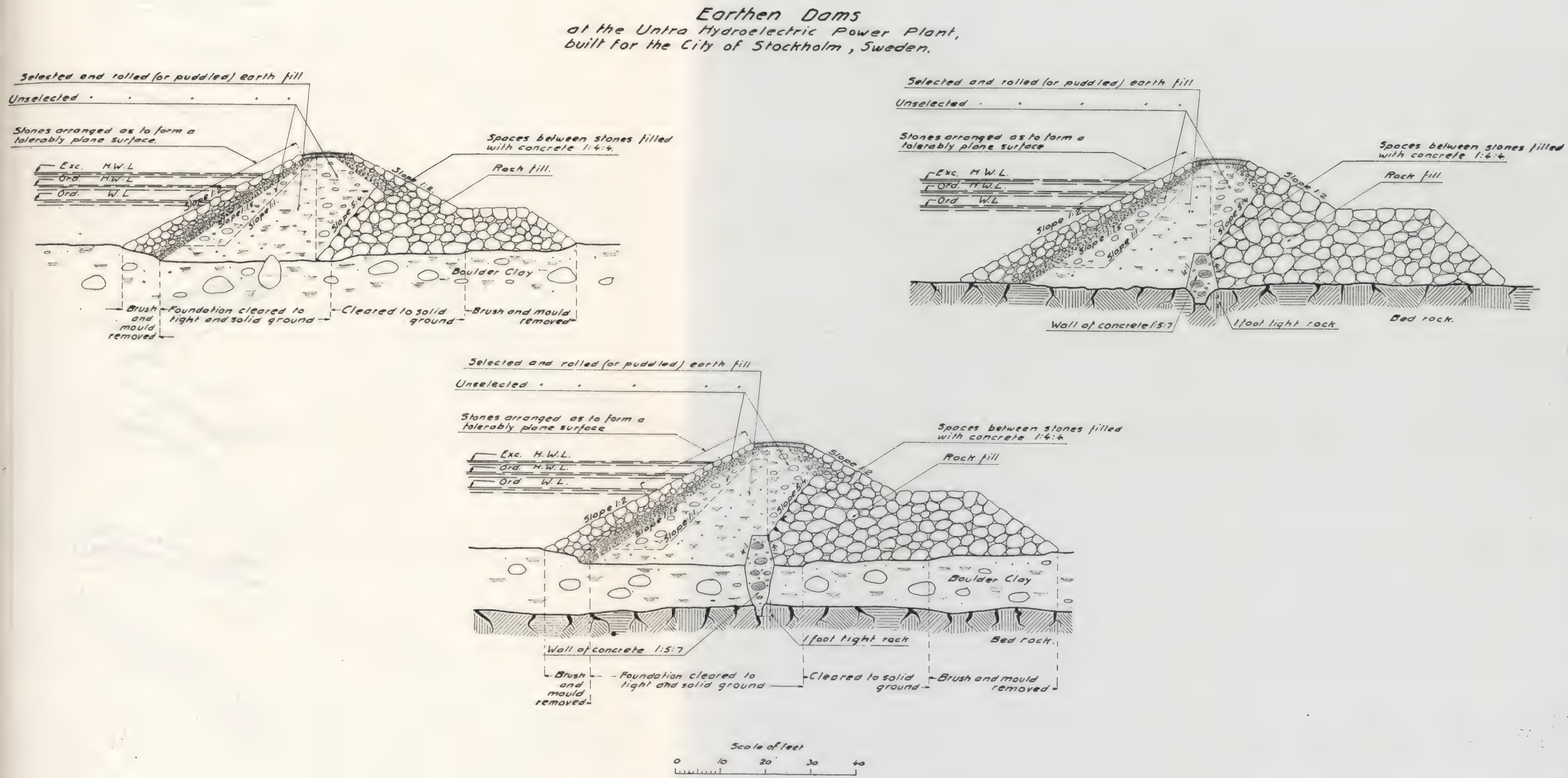

Plate IV. Cross Sections of Dykes, Untra Power Development.

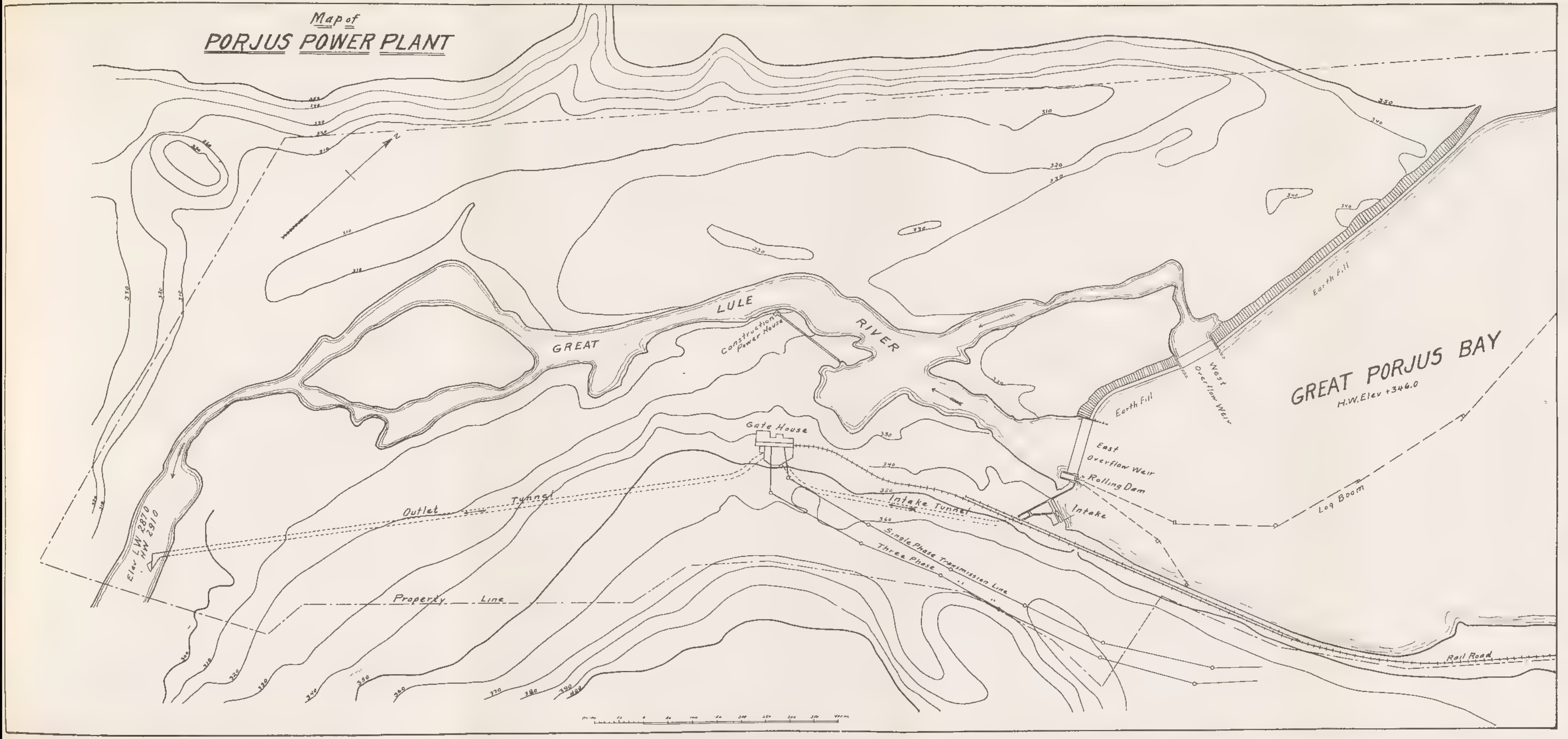

Plate V Plan of Porjus Power Development

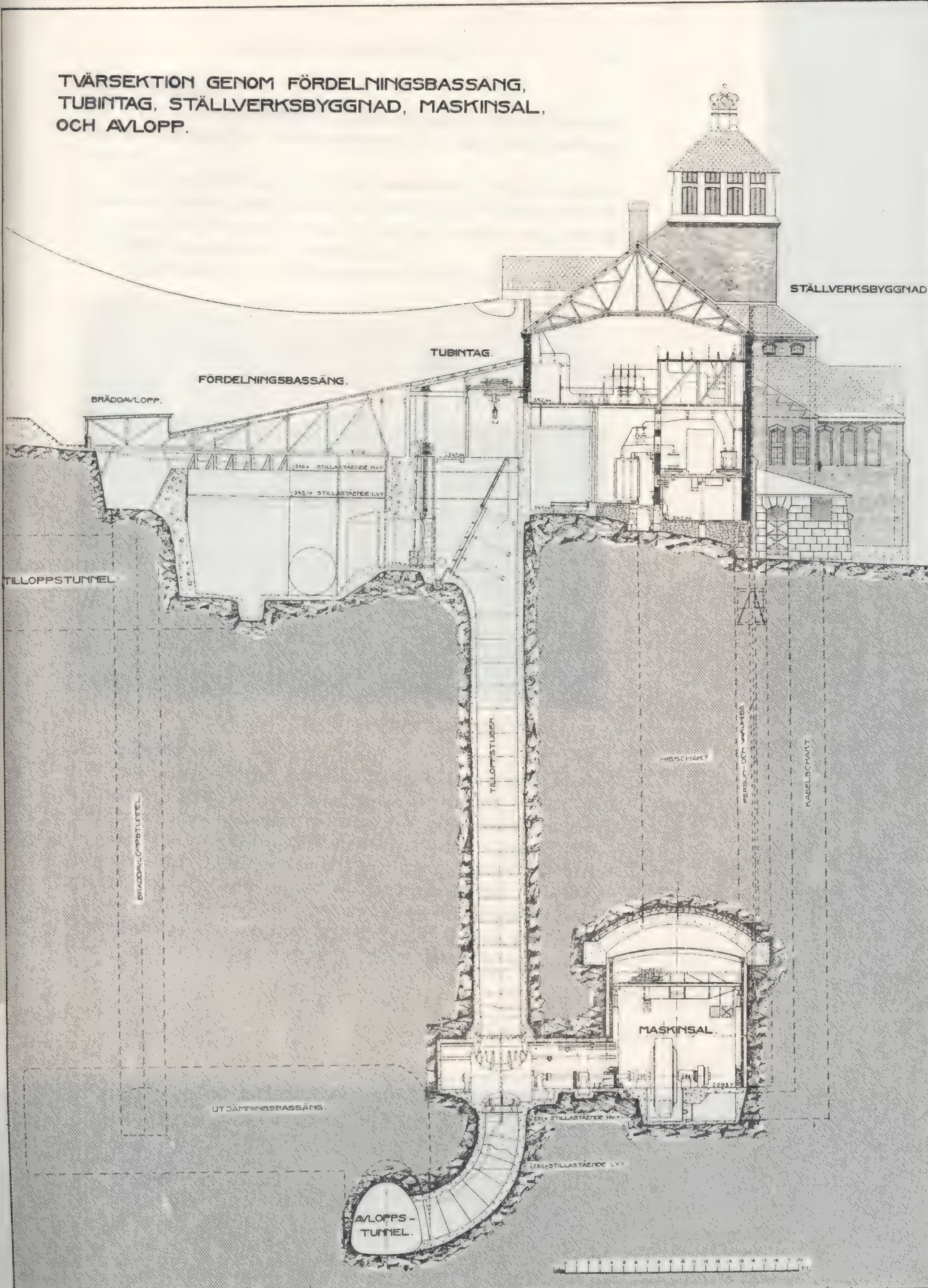

Plate VI. Section Through Porjus Power Plant.

No. 5, Dejefors.

This power development contains a dam on Klaralfven and a power station for 7000 horsepower with inlet and discharge tunnels.

The principal feature of this installation is the regulating device of the dam, which has two openings of 30 meters (98.42 ft.) clear width each, closing by rolling shutters 3½ meters (11.48 ft.) in diameter. (See Fig. 12.)

Constructors: C. J. Mangell and Vattenbyggnadsbyrån.

Fig. 11. Exterior View of Gullspång-Munkfors Co.'s Power House.

No. 6, Mockfjärd.

This installation is located on Vesterdalälfven and utilizes a 30-meter (98.42 ft.) hydraulic head. It contains a diverting dam in the river, a power station in solid rock excavation, and two discharge tunnels each 1600 meters (5249 ft.) in length. (See Fig. 13.) The diversion dam when fully constructed will back up a cascade stretch 10 meters (32.81 ft.) in height. The dam is built of concrete with pier openings covered with steel plate. The discharge openings are of varying depth and are closed partly by wooden shutters and partly by steel shutters, which

latter are 10 meters (32.81 ft.) deep and 6 meters (19.68 ft.) wide. This large gate is horizontally divided and is supported on rolling guides. It is operated by means of motor-driven chains. In order to provide for log driving, there are two logging gates 14.5 meters (47.57 ft.) in width and 3½ and 2½ meters (11.48 and 8.2 ft.) in depth, to be used according to various stages of water. At low-water period timber is carried past the falls by means of a steel flume line 2 kilometers (1.24 mi.) in length.

The power station has four turbine chambers of cylindrical shape, partly constructed of steel plate covered concrete. In

Fig. 12. Rolling Dam of Dejefors Power Development.

these turbine chambers there are twin turbines of 6000 horsepower each. There are also two exciting systems. Behind the turbine chambers is the generator room, located in an excavation in solid rock. This is provided with special ventilating facilities and the generator room is reached by an inclined tunnel with tracks and also by means of staircases. The regulating gates and inlet are housed in a special building above ground.

This installation delivers power principally to its owners, Stora Kopparbergs Bergslags A. B., and Grängesbergs Grufbolag. The cost is approximately 3.8 million crowns ($1,026,000).

Constructor: A. Landen, Grängesberg.

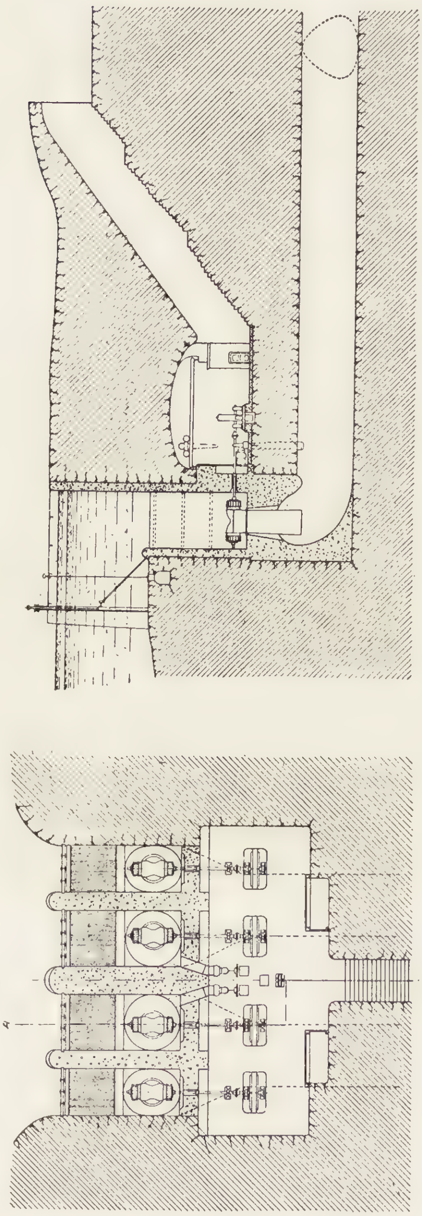

Fig. 13. **Plan and Section of Mockfjärd Power Plant.**

No. 7, Bullerforsen.

This installation belongs to Stora Kopparbergs Bergslags A. B., and consists of a dam in Dalälfven in connection with a power station on the right-hand bank and a short discharge canal, all of which is on rock foundation. (See Figs. 14 and 15.) The dam is constructed on a curve, so as to get a sufficient length to carry off flood waters at relatively small depth of submergence. At times, floods amount to 2000 cu. meters (70,630 cu. ft.) per second. The dam is constructed of concrete, and the main

Fig. 14. Dam and Power House, Bullerforsen Development.

body of the dam consists of arches supported on piers. The discharge openings are closed by shutters of wood between movable supports of I-beams. In this locality as much as 16 million pieces of timber are passed during the timber-driving season, and this timber is usually carried through by means of a center opening 25 meters (82.02 ft.) wide; the opening is reinforced with rails to prevent abrasion. When the water supply is insufficient for driving through the center gate, the timber is taken past the installation by means of a flume.

The power station contains six quadruple turbines, each 4000

horsepower. The turbines are erected in open chambers, which may be closed by large iron shutters operated by motor-driven hoists. There are two exciter units, each of 450 horsepower, with the turbines erected in separate chambers supplied with water by means of tubes coming from two intakes alongside the main intake. The generator room and the gate-regulating house are constructed of brick with concrete roofs.

The power is used for the Company's own iron works and

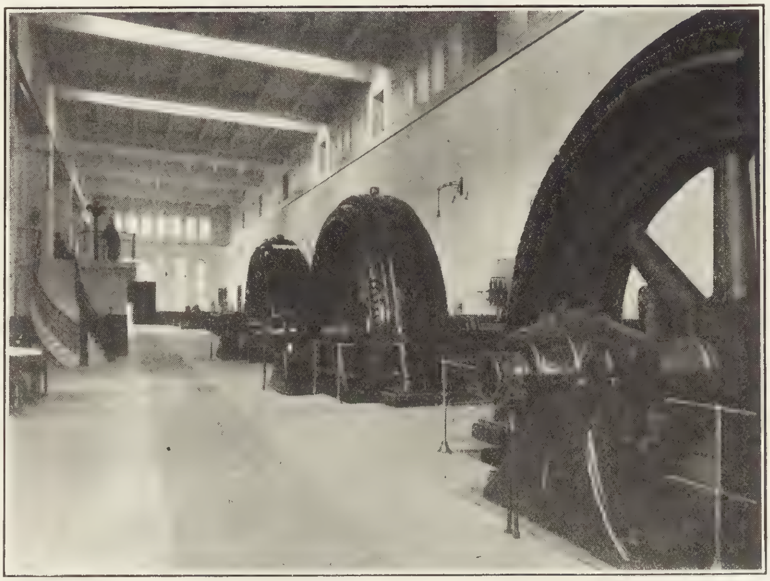

Fig. 15. Interior of Power Plant, Bullerforsen Development.

paper mill. The total cost for the power station was 3.6 million crowns ($972,000).

Constructors: L. Yngström and O. Forsgren, Falun.

No. 8, Untra.

The River Dalälfven, below the Untra Bay, forms a great number of branches and these branches cut through the glacial drift formation in a number of waterfalls. The Untra Power Station collects all the water of the river and utilizes the power of all the separate waterfalls in the power plant for the city of Stockholm. To effect the diversion of the water, the branches

of the river are closed by masonry dams and long earthen dykes; the open waters of the Untra Bay submerge the delta lands and are carried to a power station, where the turbines are installed with open intakes. The discharge canal has a length of approximately one kilometer (3280 ft.). Considerable work was necessary for the clearing and lowering of that branch of the river wherein this canal discharges. The location of the impounding works and the general arrangement of the power project are shown on the location map. (See Plate III.)

The dykes are of particular interest; they were erected by using the waste material from the excavation work. Broadly speaking, they consist of a well-puddled mass that is covered by a stone revetment, upstream, and on the downstream side supported by a heavy bank of quarried rock. Where the earth rests against the rock-fill, the surface has been spalled and covered with concrete. The puddle material came from the powerhouse excavation and was a mixture of clay and glacial drift. The downstream supporting rock-fill came from waste way excavation in the rock and boulder formation. Detailed construction is shown on Plate IV.

The project will develop ultimately 40,000 horsepower and is intended to be completed in 1917, together with the transmission line, 150 kilometers (93.2 mi.), to Stockholm.

The estimated cost is 8.6 million crowns ($2,322,000) for grading and buildings and 2.4 million crowns ($648,000) for powerhouse equipment.

Constructors: The City Engineer's Office; Mr. F. Enblom, and Vattenbyggnadsbyrån.

No. 9, Älfkarleby.

The Älfkarleby Falls are separated by two islands into three branches: the Stor Falls and the Mellan Falls, which are very steep, and the Kings Vein branch, which runs down in a series of cascades. (See Fig. 16.) These latter have always been kept open for a fish-way. The right of damming these branches has been acquired and fish-ways have been installed. The power station and the distributing system, which are located in the eastern portion of central Sweden, have been built by the State, under the direction of the Water Falls Direction. It was opened in June, 1915. The main features of the project are dams clos-

ing the three river branches and some minor dykes on the island and the shores of the river; also an inlet canal approximately 250 meters (820 ft.) long on the right hand side of the river near Stor Falls, a power station with open turbines, and a tail-race approximately 100 meters (328 ft.) long to the river. The original height of the falls was 15 meters (49.2 ft.); this has been increased to 18 meters (59.06 ft.) by impounding dams.

The foundation of the dams is largely solid rock and they are provided with discharge openings in each of the three branches of the river, so that the distribution of water in the

Fig. 16. Alfkarleby Falls.

three branches remains approximately the same as at present, which was considered desirable for aesthetic reasons. In the dams are fixed discharge aprons for a total length of 250 meters (820 ft.) on a weir-height level of normal water surface. In the Stor Falls there are four steel shutters 10 meters (32.81 ft.) wide and 3.6 meters (11.81 ft.) high in the central part of the dam. The Mellan Falls have a rolling dam 2.1 meters (6.89 ft.) in diameter and 20 meters (65.62 ft.) long, by means of which most of the ice drift can be taken care of; water is at that time usually plentiful. In the Kings Vein Branch there is a steel gate 10 meters (32.81 ft.) wide and 2.5 meters (8.20 ft.) high, so as to

always be ready to discharge a large quantity of water into this branch if the fishing interests so demand. The turbines are 5 quadruple Francis turbines on horizontal shafts, designed to deliver 14,000 horsepower at a head of 15.6 meters (51.25 ft.). They are placed in chambers of reinforced concrete, which have

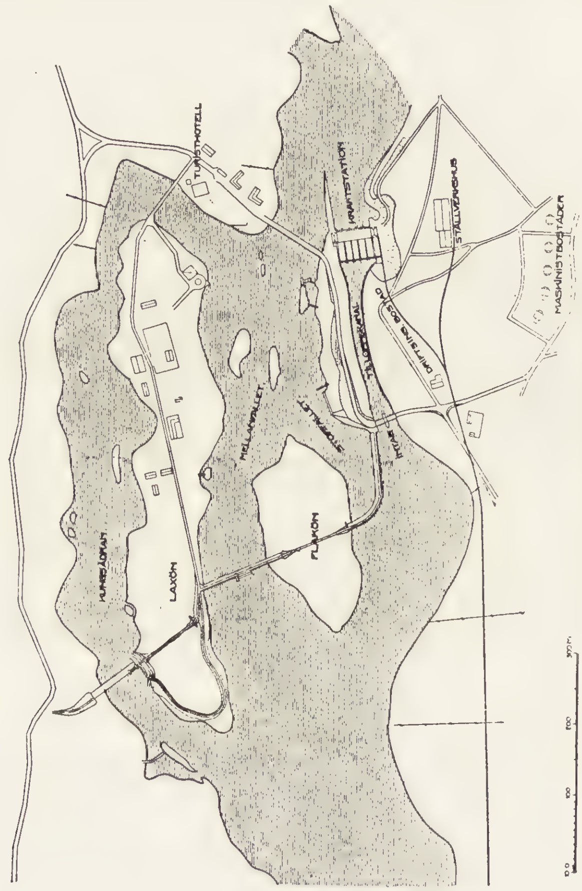

Fig. 17. Plan of Älfkarleby Project.

a depth from bottom to the top of not less than 20 meters (65.62 ft.). (See Figs. 17 and 18.) Each chamber can be closed by a steel gate 7.3 meters (23.95 ft.) wide and 9.0 meters (29.53 ft.) high. The gates are electrically operated and run on rollers combined into trucks. Inside of the gates, at the upper portion

of the chambers, there is a grizzly. That part of the chamber towards the powerhouse is semi-cylindrical.

The powerhouse contains five 3-phase generators, each for a normal rating of 10,000 and maximum rating of 12,500 K. V. A.

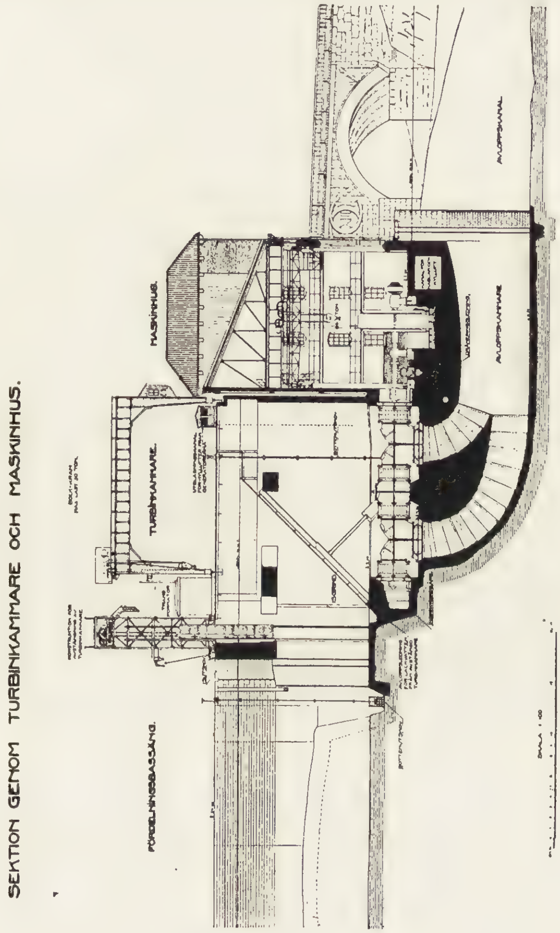

Fig. 18. Section Through Älfkarleby Power House.

at 50 periods and 10,000-11,000 volts tension. The generators are direct connected to the turbines.

There are direct-current generators on the end of the main shafts to provide excitation current, together with a direct-current installation of 220 volts in the gate house as reserve.

The gate house is located about 100 meters (328 ft.) from the powerhouse and is connected thereto by electric cables. The gate house holds the transformers and also the switchboard for the 3-phase power control, station pumps, and holders for water and oil; repair shop, laboratory and office.

The estimated cost is 6.8 million crowns ($1,836,000) for conduits and buildings, and 2.4 million crowns ($648,000) for powerhouse equipment.

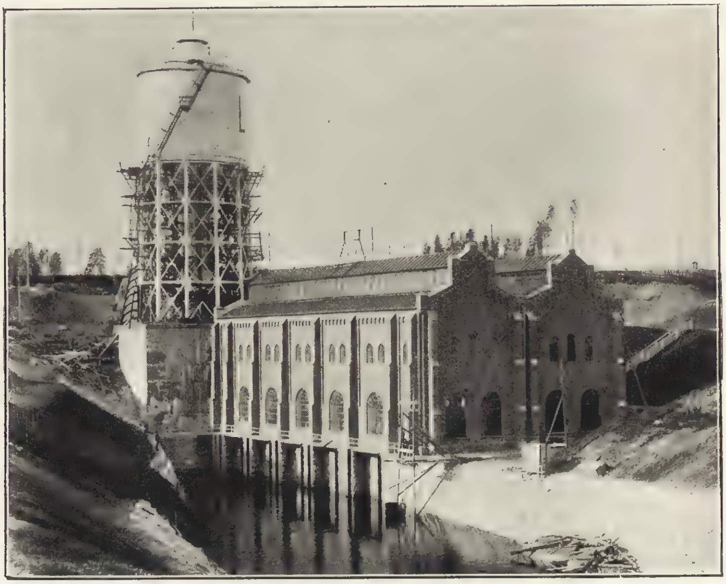

Fig. 19. Power House, Ljunga Development.

Constructor: Water Falls Direction. (Preliminary plans by Vattenbyggnadsbyrån, Stockholm.)

No. 10, Ljunga Works.

This installation belongs to the Stockholm Superphosphate A. B., and utilizes a fall of about 40 meters (131 ft.) in the River Ljungan, developing 17,000 horsepower, used in the manufacture of carbide and cyanamide. The installation consists of a diversion dam, diversion canal, steel penstock 2400 meters (7874 ft.) long with pressure tower, powerhouse and discharge canal. (See Fig. 19.) The long penstock is of particular interest. It has a

diameter of 5 meters (16.40 ft.), and is largely a horizontal tube built of steel plate, 6 millimeters (0.236 in.) in thickness, with stiffening rings. It is placed on masonry supports 6 meters apart (19.68 ft.). The standpipe has an overflow discharge into the tail-race. On account of the very severe winter climate it has been necessary to cover the standpipe with timber.

Constructor: F. B. Stafsing, Stockholm.

No. 11, Finnfors.

This is a development at Skellefte River and utilizes a fall of 20 meters (65.62 ft.). It is owned by the city of Skellefte, and the power is used by the municipality and for pulp industry. The dam forming a portion of the project is notable on account of the Bear-trap gates of American design that have been used. As far as known, this is the only use in the Scandinavian countries of this construction. The water is conducted by means of tunnels and tubes to the power station, at present installed for 9000 horsepower, but intended to be increased to 20,000 horsepower. (Fig. 20.)

Constructor: The Engineering Bureau of Unander and Jonson, Stockholm.

No. 12, Porjus.

The Porjus power plant belongs to the State and supplies power for the electrification of the Boundary Railroad and for the ore fields of Gellivare and Kiruna. The plant uses the head between low water in Great Lule Lake and the water surface at Little Porjus Bay just below the Porjus Falls. The falls are shown on Figure 21. The effective head varies from 49 to 55 meters (160.7 to 180.5 ft.). A dam below Great Porjus Bay raises the water surface 10 meters (32.81 ft.), to the low-water surface of Great Lule Lake.

Supply and discharge for the turbines are by means of tunnels, 325 and 1275 meters in length (1066 and 4182 ft.). The inlet opening is at the left end of the dam. (See Plate V.) The dam is 1250 meters (4100 ft.) in length and extends over two branches of the river. To a large extent it is an earth dyke, particularly on the right-hand bank of the river.

The main dam is located immediately adjoining the tunnel intake. Then follows a rolling dam 12 meters (39.37 ft.) in free width to provide for timber driving and these aprons 200 meters

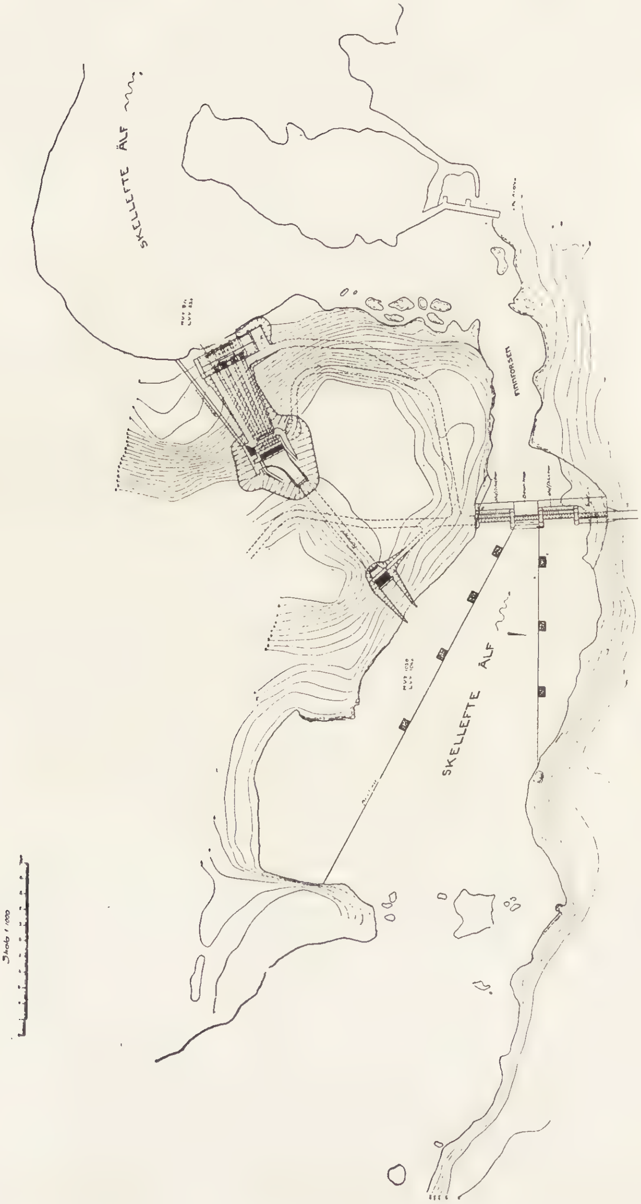

Fig. 20. Plan of Finnfors Development.

(656.2 ft.) in length. The earth dykes are 1000 meters (3280 ft.) in length over the island in the river, and on the right-hand bank.

Ice pressure has been given special consideration in the construction of the dam, on account of the heavy ice cover on Great Porjus Bay, that often reaches a thickness of 1 meter (3.28 ft.). Where the dam is most exposed to ice pressure, it has an earth embankment on the upstream side and a supporting rock fill on the downstream side; in the center is a heavy core-wall of rein-

Fig. 21. Porjus Falls.

forced concrete. The upstream side is also protected by means of heavy rock revetments. When heavy ice pressure occurs, it is contemplated that the earth filling may be compressed without the dam itself receiving any damage. The ice is also forced upwards over the dam on account of the flat slope of the upstream side. The aprons are constructed of reinforced concrete and are protected on the water side by earth embankments and rock filling.

The intake is divided into four openings, 11 meters (36.08 ft.) wide. The two openings immediately adjoining the dam are

intended for the first installment of 100 cu. meters (3520 cu. ft.) per second. The gate arrangement for each opening consists of one large steel shutter placed behind a grizzly and carried on rollers combined into trucks. The area of the inlet tunnel is approximately 50 sq. meters (538.19 sq. ft.), and for the next development a tunnel of equal size is to be built. The tunnel discharges into a covered forebay provided with an overflow weir that discharges into a branch tunnel 5 meters (16.40 ft.) in diameter connecting to the main discharge tunnel. This is in order to provide for waste of water on account of regulation.

Directly connected to the forebay are 5 turbine chambers, consisting of shafts 50 meters (164.04 ft.) in depth, steel sheeted, 3.5 meters (11.48 ft.) in diameter and blasted in solid rock. Each chamber has a grizzly behind regulating gates. In the bottom of the chambers the turbines are located [12 meters (39.37 ft.) center to center] in cylindrical casings, each in a niche of the generator room.

The generator room is 50 meters (164.04 ft.) under rock surface, and will contain electric generators and turbine governors. The first installation consists of 4 units; 3 of these are of 10,000 normal and 12,500 maximum turbine horsepower, and the fourth, 12,500 normal and 14,000 maximum turbine horsepower.

Two turbine units are direct-connected to single-phase generators for the electrification of the railroad. The third unit is intended for the power of the ore fields of Gellivare and Kiruna and has a 3-phase generator. The turbine of the fourth unit is direct-connected both to a single-phase and a 3-phase generator, to act as reserve both for the railway power and for the general power distribution; excitation is provided by means of a direct-current generator connected to a 525-horsepower turbine with separate supply tunnel 0.85 meters (2.79 ft.) diameter.

The draft tubes of the turbines consist of steel plate tubes laid in solid concrete placed in tunnels that discharge in the general discharge tunnel. The latter is provided with compensation galleries to absorb pressure changes at load fluctuations.

The gate house is above ground, vertically over the generator hall and is constructed of brick. It contains transformers, switchboards, control station, pumps and tanks for water and

oil, store rooms, operating office, etc. The building is connected to the generator hall by a large elevator shaft and a separate cable shaft.

This power development is the most northerly large development in the world. Complete construction for four units will cost 11.5 million crowns ($3,105,000).

Constructor: Water Fall Direction.

APPENDIX No. 2.

LEGISLATION, GOVERNING AUTHORITIES, AND ORGANIZATIONS ACTING CONCERNING WATER POWER IN SWEDEN.

Swedish water law acknowledges, as a rule, the owner of the river bank as the owner of the water and the water power in front of his property, and there is no doubt that this private ownership to water power has been a powerful incentive for its development. Alongside of this private ownership there is, in larger water courses, a general community interest to be preserved, and this has found its expression in the ancient institution of ''Kings Vein'', which consists of the middle third of the water course at ordinary low water. This is to provide for the needs of navigation, timber driving, fish migration, etc.

Our present water law was largely adopted in 1880. It is consequently not fully in keeping with modern requirements for power development. The law was somewhat revised in 1899, with impracticable regulations regarding construction encroaching upon the Kings Vein. In 1902, a law was adopted which included technical requirements regarding rights of way for transmission lines (on a 40-year license basis), together with right of eminent domain of such purposes.

Important laws are at the present time being considered for the control of water power development. In the year 1910 there was submitted a comprehensive proposal for a new water law. It intended in the first place to provide practical means for rational regulation of lakes and water courses, including, among other things, provision for coöperation between owners of waterfalls and rapids for their consolidation. There was also proposed a simplified procedure in water-right litigation.

Recently there have been proposals for new laws regarding timber driving and new laws regarding contracts for supply of electric energy. There has also been extended investigation regarding the possibilities of various kinds of power distribution in Sweden. The Permanent Committee on Laws does not, however, consider that there is any necessity for legislation affecting economic conditions.

For some years past, certain parties have proposed establishment of franchise concessions of various kinds in connection with the development of water power or location for transmission lines, according to foreign practice. Later years appear, however, to have established a growing knowledge of the peculiar conditions under which Swedish water-power industry must develop, giving some hope of a practical solution of the many law projects, but this solution is hardly to be expected before the year 1917.

The government of Sweden has, in the last few years, by suit, made claim on a large amount of power, independent of shore owners' right, in the large rivers in Norrland. These demands have, however, been largely rejected by the courts, but in the meantime several owners of waterfalls have been prevented from developing their power. In the year 1910-11 regulations were adopted for licensing power users of the waterfalls of the State, with provisions for mortgaging the license right. License was for a period of 60 or 75 years: For 60 years, with payment for works on termination of license; and 75 years without payment for works at termination of license. These requirements were also intended to apply to water power in litigation, but they have found no use whatsoever and are evidently not suited for regulation of new development in Norrland. During recent years, requirements have been changed so as to permit licensing for 85 years in succession, with right to payment for works at termination of the period, if new license is not granted. However, if the State should lose in litigation now in progress, even these requirements will disappear.

In earlier years water-power questions were principally handled by the Royal Direction of Roads and Waterways. This Direction, together with other authorities, still passes on questions regarding building in the ''Kings Vein''. Legislation

affecting electrical developments in 1902 established the Board of Electrical Inspection under the authority of the Department of Commerce (four inspectors for Sweden).

Since 1908 the Hydrographic Bureau has been systematically collecting data regarding water-courses, according to the same program that governs similar institutions in other countries. In 1909 the Water Falls Direction was organized, and the following power developments have been carried out under control of this Direction: Trollhättan, Porjus and Älfkarleby.

Some private organizations may also be mentioned: the Swedish Water Power Association, an organization that includes corporations, municipal and private water power owners and private persons as members. This Association was organized in 1909, principally for the purpose of furthering Swedish water power development by technical, economical and legal investigation.

The Electric Power Association of Sweden is an organization of the larger portion of the big electric power plants.

Vattenbyggnadsbyrån (The Hydraulic Engineering Bureau, Inc.), is a firm of consulting engineers founded in 1902 by Prof. J. G. Richert. This organization has designed and constructed a number of water power developments and river regulations, both in Sweden and in foreign countries for municipal or private owners.

DISCUSSION

Mr. Haar. **Mr. S. Haar,*** Mem. A. I. E. E., said that he had investigated high-tension power systems all over the world, but found at Porjus the only single-phase high-tension plant. This plant operates at 80,000 volts.

Mr. Beckman. **Mr. J. W. Beckman**† called attention to the enormous possibilities on the Pacific Coast for water-power development. In Washington, Oregon and California, there are approximately 11,000,000 h.p. available in water-powers. Here, also, many large plants are capable of very large extension like the Big Bend, the Dalles, and others. He considered the most interesting parts of this paper to be those dealing with applications of power. In Sweden, raw materials must be imported. In the United States we are fortunate in having at hand large amounts of raw material for electro-chemical development, and we have a favorable climate. Also, while Sweden must depend largely on foreign capital for her development, rendering it very difficult, we have here the necessary capital available in the country itself.

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Paper No. 145

CANADIAN HYDRAULIC POWER DEVELOPMENT.

By

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INTRODUCTORY.

In the presentation of this paper, it is intended to especially deal with the progress in hydraulic power utilization in the Dominion of Canada; to discuss some of the features involved in the design, construction and operation of hydraulic plants which have found special application, and to incidentally describe a number of typical Canadian power developments.

The Dominion of Canada, lying entirely northward of the United States and stretching from the Atlantic to the Pacific Ocean, embraces a variety of climates and a wide range of topographical features which include, possibly, all favourable and unfavourable characteristics, insofar as development of hydraulic power is concerned. The water powers of the Dominion are almost limitless, and while a great majority are very remote from consuming centres it is inconceivable, notwithstanding any radical changes in the art of power transmission, that the water powers would ever be completely commercially developed. The cities of Canada are fortunate in being, without exception, within the zone of economic electrical power supply from hydraulic sources.

Engineers, manufacturers and financiers of the world have an appreciably marked influence directly upon the conducting of engineering undertakings in Canada on account of the economic relations of the Dominion with Great Britain, the United States and the Continental countries. The bulk of the financ-

ing of large works is undertaken in England. While complete mechanical equipment of very high grade, made entirely in the Dominion, is obtainable, and the customs tariff levies a duty on imports from all countries, it must be appreciated that the manufactures of Great Britain, France, Germany, Switzerland, Italy and Sweden, and the United States are available in Canada on a competitive basis. This is true of practically all machinery and materials, so that in practice it transpires that an equipment may be assembled from many different sources, requiring on the part of the engineer the harmonizing of the designs of these individual parts of varied origin.

While the first half of the last twenty years initiated the radical advances in the whole field of hydraulic engineering, the last decade has been notable for the increase in capacities and efficiencies and for the refinements in design of the various components of the power developments.

It cannot be said yet that hydraulic engineering is approaching a condition possible of complete standardization. Every development shows a combination of features requiring an individual arrangement and design, and it is apparent that within the last few years notable strides have been made with the development of dams, conduits, turbines, regulating devices and so forth.

Rather than deal exhaustively on one subject or too briefly on all, the general considerations of many of the features and problems of contemporary hydraulic engineering will be undertaken in what follows. It is to be noted that reference is made to the subjects of storage of water for power purposes and to the ice problems; the former is now engaging the Dominion Government and the Governments of several Provinces, aiming at the improvement of rivers for power and navigation purposes; the problem of the freezing of water has always been a serious one, but it is now almost universally successfully dealt with.

WATER STORAGE.

Storage of water for power purposes by no means presents a new problem, but the application to the immense power proj-

ects now existing or under way demands a systematic conservation of water quite beyond the requirements of the past and introduces many new phases into the question.

The seasonal changes in river flow are very pronounced, as the winter discharge is, in general, retarded by freezing and in the late summer the combined effect of low precipitation, excessive evaporation and depletion of natural storage again creates low water; the lesser flow of the two periods definitely determining the economic value of the water power. The enormous flood flows following the winter seasons are available for but a very short period, but if properly conserved and further augmented by the storage of the surplus of the subsequent rains, the minimum flow can be materially increased and the value of the benefited power developments correspondingly raised.

The condition is general in Canada, that hydro-electric developments have approached or exceeded the unregulated capacities of their respective rivers, and while very few extensive storage systems are as yet constructed, the activity of industrial expansion now demands that the power developments must anticipate the very near future and fully provide for the securing of maximum available outputs and that every advantage be taken for complete conservation and storage. It is remarkable that practically all Canadian rivers are naturally provided with excellent storage possibilities.

Pondage, differentiated from storage as being the day-to-day storage of water immediately available at the turbines, is an essential in Canadian water powers as providing an insurance against ice, which, as later described, is a factor commanding the full respect of the engineer. The river flow due to the controlled discharge from remote storage reservoirs may not correspond to the variation in power demand during the day, thus, further necessitating pondage as an important component in the economic regulation.

The investigation of storage and pondage requirements must fairly establish the load factor of the power supply imposed on the system, the load distribution over the twenty-four hours, and, further, the seasonal variation of load as dictated by the nature of the market. The study of the unexploited field de-

mands an approximation of loads, whose character may be assumed by comparison with other existing loads, and it is essential that the inherent load factors applicable to the respective types of loads be fully recognized.

It must be appreciated that effective storage requires relatively large areas of land for flooding purposes and such lands, by growth of population and by the establishment of permanent improvements, increase in value at a rapid rate; at the present time, however, it transpires that the majority of the Canadian storage schemes now under way involve remote forested Crown lands readily adaptable for storage purposes. The multitude of interests involved in extensive storage developments makes the accomplishment of storage, in most cases, quite beyond the capabilities of the power developing companies and requires concerted action in the obtaining of the necessary rights. In Canada, the respective Government, Dominion or Provincial, which has jurisdiction over water powers acts as the intermediary and this has been a very substantial factor in the notable success of the power situation throughout the country.

The Government of the Dominion of Canada has full control of all navigable and floatable streams and, in addition, through the Water Power Branch of the Department of the Interior, controls all water power developments and possibilities in the Provinces of Manitoba, Saskatchewan, Alberta and the Northwest Territories and the Yukon, and follows a policy of encouraging legitimate enterprise for the development of power resources.*

In the Province of Ontario, the Department of Lands, Forests and Mines, in conjunction with the Hydro-Electric Commission of Ontario, controls the water powers on other than navigable streams. The Hydro-Electric Commission is virtually a government commission acting in trust for the various municipalities which have combined for the securing of cheap power; the influence of the Hydro-Electric Commission tends to the development and distribution of power under public ownership. The extent of the operations of this commission is very

* See reports of Water Power Branch, Department of the Interior, Canada.

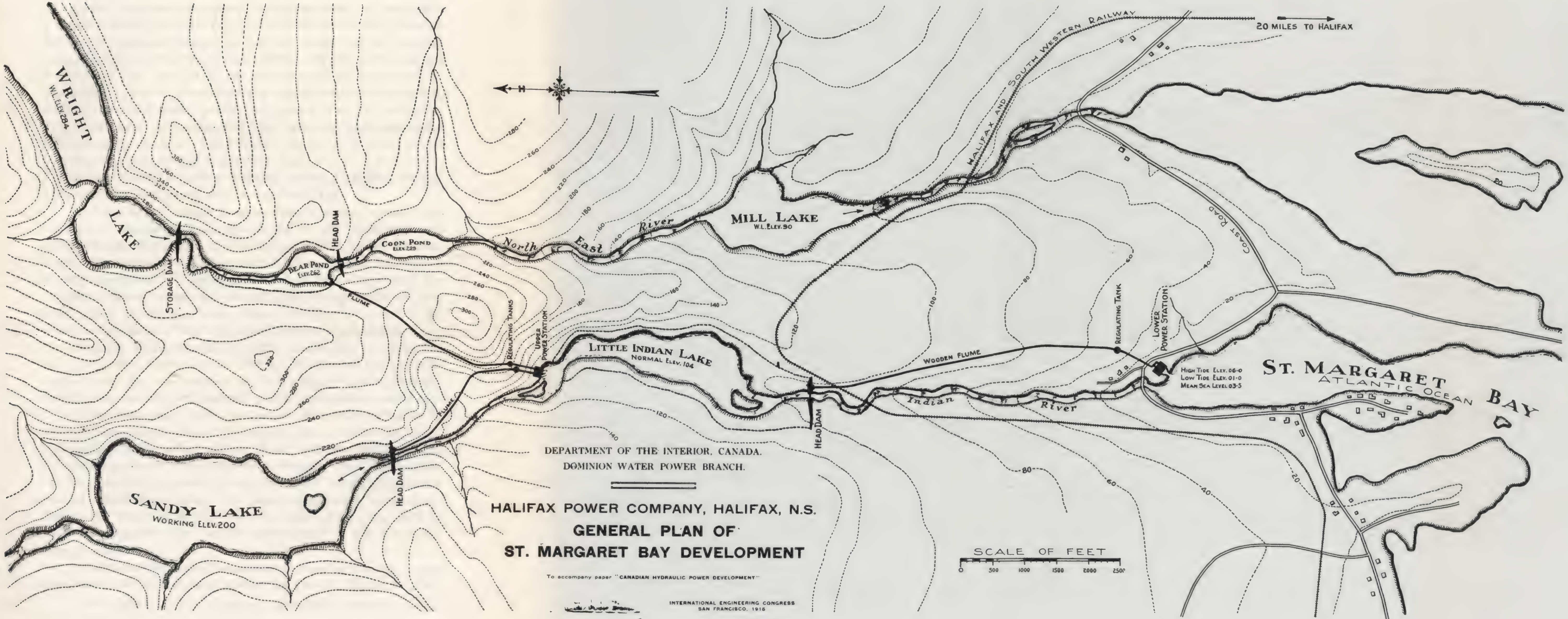

WRIGHT LAKE
W.L. ELEV. 284
STORAGE DAM
HEAD DAM
BEAR POND
ELEV. 262
COON POND
ELEV. 229
FLUME
North East River
MILL LAKE
W.L. ELEV. 90
HALIFAX AND SOUTH WESTERN RAILWAY
20 MILES TO HALIFAX
REGULATING TANKS
UPPER POWER STATION
LITTLE INDIAN LAKE
NORMAL ELEV. 104
WOODEN FLUME
REGULATING TANK
LOWER POWER STATION
HIGH TIDE ELEV. 06-0
LOW TIDE ELEV. 01-0
MEAN SEA LEVEL 03-5
COAST ROAD
ST. MARGARET BAY
ATLANTIC OCEAN
Indian River
HEAD DAM
SANDY LAKE
WORKING ELEV. 200
HEAD DAM
DEPARTMENT OF THE INTERIOR, CANADA.
DOMINION WATER POWER BRANCH.
HALIFAX POWER COMPANY, HALIFAX, N.S.
GENERAL PLAN OF
ST. MARGARET BAY DEVELOPMENT
To accompany paper "CANADIAN HYDRAULIC POWER DEVELOPMENT"
INTERNATIONAL ENGINEERING CONGRESS
SAN FRANCISCO, 1915
SCALE OF FEET
0 500 1000 1500 2000 2500

Fig. 1.

great and calls for a consideration quite beyond the scope of this paper.†

In the Province of Quebec, the Department of Lands and Forests controls the power in Provincial waters, and through the Quebec Streams Commission has now under way an immense storage project on the St. Maurice River. Water powers of the Province of New Brunswick are administered by the Provincial Government, but in Nova Scotia a great portion of the land, with the included water powers, has passed from the control of the Government; the remaining sites, however, continue under full Provincial control. The Province of Prince Edward Island is without powers of any magnitude.

It must suffice to briefly describe several Canadian storage developments now under way or contemplated.

In Nova Scotia, about 16 miles from Halifax, a small, yet interesting scheme is being developed on the Northeast and Indian Rivers which flow into St. Margaret Bay on the Atlantic Coast. The water available in each of these distinct watersheds is fully conserved by storage dams and the water from the Northeast River is carried over the intervening height of land to the No. 1, or Upper, Power House (See Fig. 1), in which the water under each of the two heads serves a generating unit, the discharge being into Indian Lake, at the foot of which the No. 2, or Lower, Power House is situated, with tail race at tide-water level. By conservation, the low summer flow is doubled, thus making such a development a good commercial possibility.

On the Saguenay River, in Quebec, the outlet of Lake St. John (which has an area of 350 square miles), there are excellent natural features permitting of an enormous development, the organization of which is now well under way, contemplating an output of 1,200,000 horsepower with an initial installation of 300,000 horsepower, the immense capacity being justified by the very low cost of power in large generating units of 50,000 horsepower each, for the manufacture of nitrogen products for export.

The Quebec Streams Commission is constructing the necessary works for the storage system on the St. Maurice River,

† See "Electric Power in Canadian Industry", Electrical Section, International Engineering Congress, 1915.

which supplies the Shawinigan and Laurentide (Grand Mere) plants.* This system raises the minimum flow of 6000 cubic feet per second to 15,000 cubic feet per second, the effective drainage area being 16,200 square miles and the reservoir dam at La Loutre impounding 160,000,000,000 cubic feet. This work is undertaken by the Commission for the benefit of the present power producers, increasing the power available at the now developed sites by 122,000 horsepower at Shawinigan Falls and 63,000 at Grand Mere, and as an improvement on six unde-

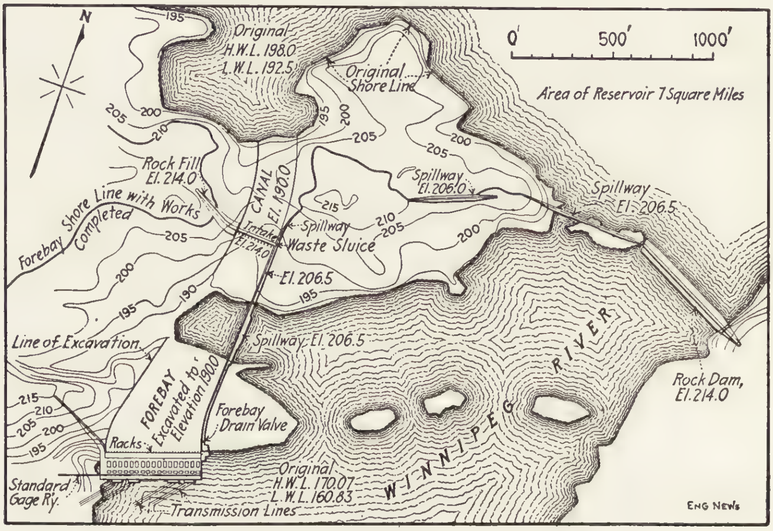


Fig. 2.

veloped sites on the St. Maurice which will thus aggregate 182,000 horsepower capacity; appropriate rentals will be charged the individual users and the costs assumed by the Commission defrayed.

Surveys have just been completed in connection with the storage possibilities on the Winnipeg River, on which two very important power plants have already been developed. The Winnipeg Electric Railway has a plant on the Pinawa Channel, making use of the Du Bonnet Falls†; at this plant 26,500

* See Second Report. The Quebec Streams Commission, 1913.

† See Electrical World, June 23, 1906.

horsepower has been developed. The City of Winnipeg Hydro-Electric plant‡ (See Fig. 2) at Point du Bois, about 77 miles northeast of Winnipeg, has an installation of eight units aggregating 51,500 horsepower output, the ultimate plant being designed to have an output of 76,000 horsepower. The Point du Bois site has a pondage of about 7 square miles above the dam. The surveys show that the minimum flow on this river may be increased from 12,000 second feet to 20,000 second feet by storage to be readily obtained in the head waters in the Lake of Woods and the Rainy River and English River watersheds, there being a combined area of 47,000 square miles drained.*

The Bow River, in Alberta, rises in the Rocky Mountains and is subjected to climatic conditions notably severe in river flow, the sources being mountain streams, glaciers and snow fields. The excellent facilities for power development on the Bow River at several locations adjacent to the power market of Calgary and the immediate requirement for regulated flow in the case of the Calgary Power Company at Horse Shoe Falls, where the minimum flow of 550 cubic feet per second was not sufficient for the market demands, induced the Dominion Government to undertake the investigation of Bow River storage possibilities, resulting in a survey and report† on the whole project and the immediate construction of the reservoir at Lake Minnewanka on the Cascade River, a tributary of the Bow, near Banff and lying within the Rocky Mountains Park. An added feature of this reservoir is that the Government proposes the installation of a hydro-electric generating plant which will use the stored water from the reservoir while in transit to the Bow River, and thus secure an ample power service for the town of Banff and the immediate surrounding portions of the Rocky Mountains Park, the whole of which has an area of eighteen hundred square miles and, to a great extent, includes all the storage areas required for the Bow River storage system, which will aggregate over 10,500,000,000 cubic feet.

‡ See ''Engineering'', London, July 26 and August 2, 1912; also Canadian Society of Civil Engineers, 1911, Proceedings.

* See ''Winnipeg River Power and Storage Investigation'', Water Power Branch, Department of Interior, Ottawa.

† See ''Bow River Power and Storage Investigation'', Water Power Branch, Department of the Interior, Ottawa.

At the present time, investigation is under way by the Water Power Branch for the creation of storage for the Athabaska River, which has its source in Northern Alberta, some miles north of Calgary. This river flows toward the Arctic Ocean; and while having its headwaters extending far above Lesser Slave Lake into the Rocky Mountains, the winter conditions are such that the minimum winter flow is approximately 2000 second feet at Athabaska Landing, as compared with the minimum summer flow of over 20,000 cubic feet. The power possibilities on this river are enormous, if the flow can be economically regulated; and the adjacent markets of Edmonton and the Peace River country—the latter Canada's Last Great West—comprise an exceedingly attractive goal.

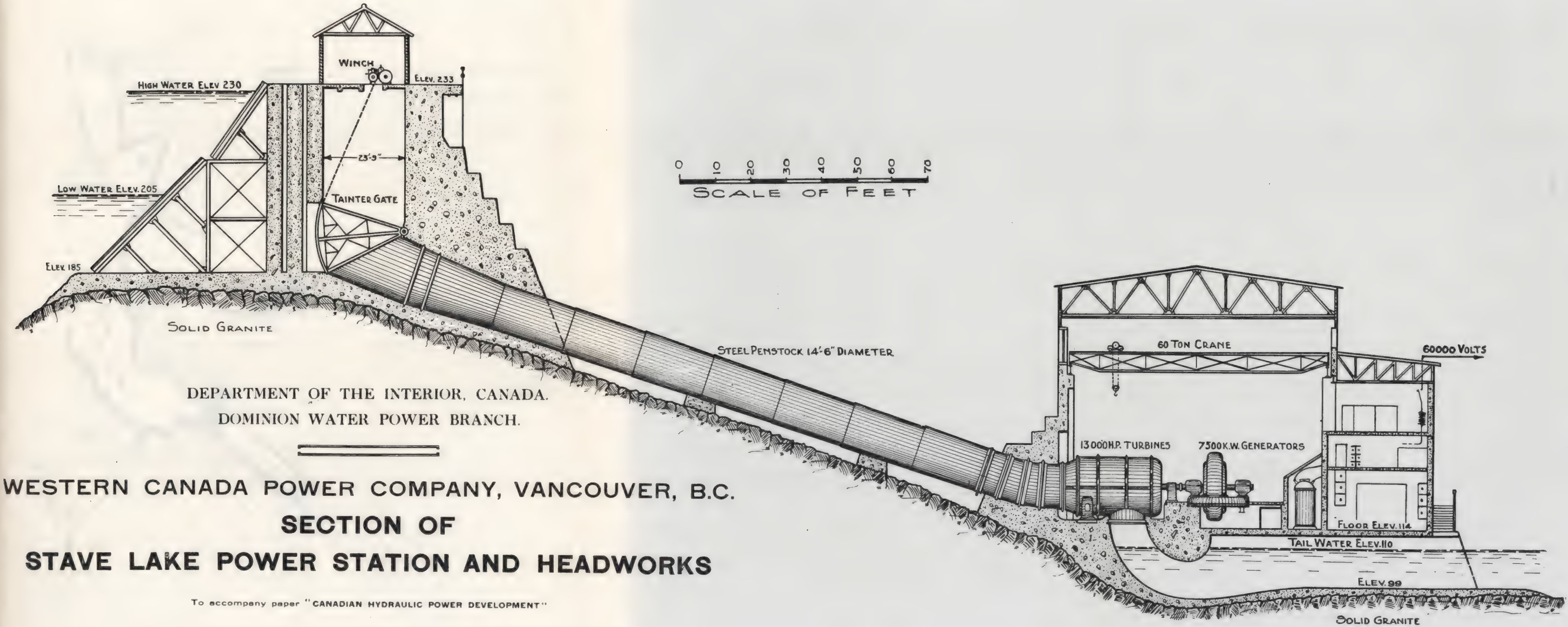
At the Stave Lake plant of the Western Canada Power Company situated 36 miles East of Vancouver, B. C., there is an available storage, immediately above the power site on Stave Lake, capable of impounding the complete run-off from the glaciers and snow fields above; this storage reservoir has a total capacity of 14,000,000,000 cubic feet, which will serve the ultimate two power sites at this point. The output of the upper plant is at present designed to be 52,000 horsepower, with 40,500 horsepower already installed.* (See Fig. 3).

The Coquitlam-Buntzen plants of the British Columbia Electric Railway Company, situated on tide water at Burrard Inlet, have an interesting system of storage utilizing two adjacent watersheds. The general scheme of development is shown in Fig 4 and is later described herein. The Lake Coquitlam storage, in which the water of the Coquitlam watershed is collected, has a capacity of 7,623,000,000 cubic feet. The rainfall is notably excessive, averaging 156 inches per annum over the last ten years.

PROGRESS IN HYDRAULIC ENGINEERING.

Progress in engineering construction and practice can possibly best be described and illustrated by reference to local applications and it will readily become apparent that Canadian plants have provided a field for, and have demanded, the devel-

* See Electrical World, New York, 1912, p. 489.



DEPARTMENT OF THE INTERIOR, CANADA.
DOMINION WATER POWER BRANCH.

WESTERN CANADA POWER COMPANY, VANCOUVER, B.C.

SECTION OF
STAVE LAKE POWER STATION AND HEADWORKS

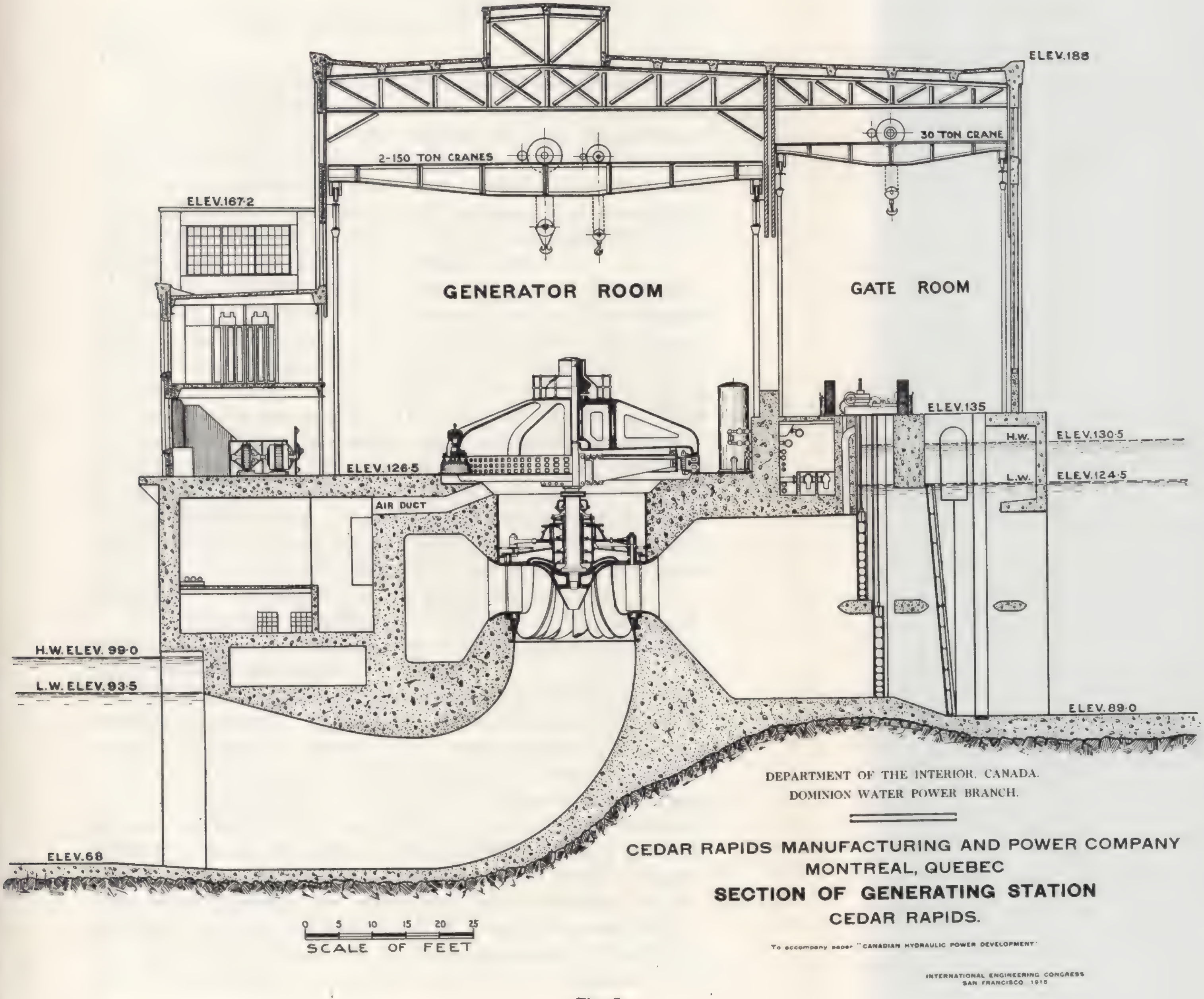
To accompany paper "CANADIAN HYDRAULIC POWER DEVELOPMENT"

INTERNATIONAL ENGINEERING CONGRESS
SAN FRANCISCO, 1915.

Fig. 3.


DEPARTMENT OF THE INTERIOR CANADA
DOMINION WATER POWER BRANCH
BRITISH COLUMBIA ELECTRIC RAILWAY COMPANY
GENERAL PLAN OF DEVELOPMENT
AND SECTION OF COQUITLAM DAM
To accompany paper CANADIAN HYDRAULIC POWER DEVELOPMENT
INTERNATIONAL ENGINEERING CONGRESS
SAN FRANCISCO 1915
SPILLWAY CREST EL 503
DAM CREST EL 518
HEAVY MATERIAL
HEAVY SLUICED MATERIAL
ROCK
SLUICED CLAY PUDDLE
98 FT.
ROCK
655 FT. OVERALL
MAXIMUM SECTION OF COQUITLAM HYDRAULIC FILLED DAM
SCALE OF FEET
0
2000
4000
6000
BURRARD INLET
PACIFIC OCEAN - HIGH TIDE EL.0.00
STATION Nº1
PENSTOCKS
STATION Nº2
SURGE TANK
TUNNEL
LAKE BUNTZEN
WATER LEVEL ELEVATION 400
COQUITLAM TUNNEL
COQUITLAM LAKE
WATER LEVEL ELEV 503
HYDRAULIC FILLED DAM

Fig. 4



ELEV.188
30 TON CRANE
2-150 TON CRANES
ELEV.167·2
GENERATOR ROOM
GATE ROOM
ELEV.135
H.W.
ELEV.130·5
L.W.
ELEV.124·5
ELEV.126·5
AIR DUCT
H.W. ELEV. 99·0
L.W. ELEV. 93·5
ELEV. 89·0
ELEV. 68
DEPARTMENT OF THE INTERIOR, CANADA.
DOMINION WATER POWER BRANCH.
CEDAR RAPIDS MANUFACTURING AND POWER COMPANY
MONTREAL, QUEBEC
SECTION OF GENERATING STATION
CEDAR RAPIDS.
0 5 10 15 20 25
SCALE OF FEET
To accompany paper "CANADIAN HYDRAULIC POWER DEVELOPMENT"
INTERNATIONAL ENGINEERING CONGRESS
SAN FRANCISCO 1915

Fig. 5.

opment of the foremost and most radical advancements in constructional features and equipment.

Turbines.

The notable advances in turbine design have been the attaining of high specific speeds and the making possible of the development of low heads by turbines of large capacities of comparatively high speeds and of a much improved efficiency. The economic utilization of low heads generally resolves itself into a vertical shaft installation, and the many persistent objections to the established form of such a construction have demanded radical changes in the turbine design.

The single-runner, vertical-shaft turbine has a very important position in Canadian developments. In the Cedar Rapids plant on the St. Lawrence River, near Montreal, the largest wheels of this type are now installed, there being twelve units of 10,800 horsepower under a head of 30 feet at a speed of 55.6 revolutions per minute. (Fig. 5.) At the Grand Mere development of the Laurentide Company, on the St. Maurice River in Quebec, similar units are being installed of 20,000 horsepower capacity under a head of 76 feet and a speed of 120 revolutions per minute. The Cedar Rapids units are much the larger and have a much higher specific speed than the Laurentide units. Up to within a few years ago, such capacities were beyond the comprehension of the hydraulic engineer.

The commercial efficiencies to be obtained from these modern high specific speed turbines are remarkably high, approaching 93 per cent and more.

The advantage gained over the multiplication of runners formerly required on one shaft to develop, under low head, a capacity economically suitable for a hydro-electric installation, are many. The simplicity of a single gate mechanism; the elimination of submerged gate gears and the torsional effects of the transmitting gate shafts; the small vertical dimensions required, conforming more rationally to the available distance between head and tail waters; the single draft tube, which may be placed more advantageously; the accessibility of mechanisms for inspection, repair and dismantling; low comparative cost of turbine, of concrete settings and water passages, and of handling; and the possibilities of concrete-formed water passages with

smooth curved surfaces and small head loss are all points whose value may be readily appreciated. The disadvantages of the high efficiency being confined to a small load range and the necessity for supporting bearings have small weight in the selection of this type of turbine. The three-quarter load efficiency compares favourably with the maximum efficiency of the lower specific-speed turbines. The development of supporting bearings of the Kingsbury, roller and ball types, has kept pace

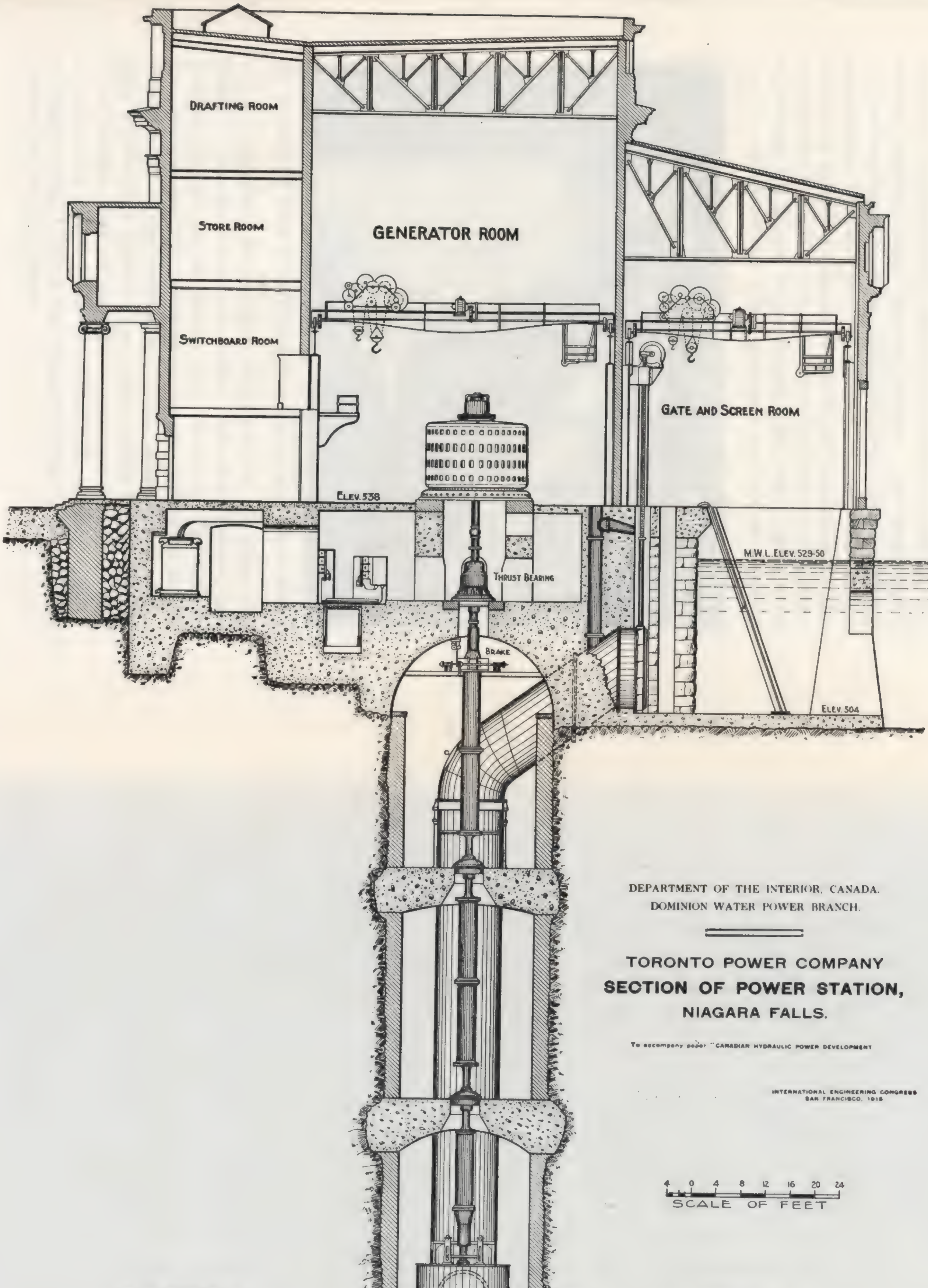
Fig. 6. Interior of Power Station, Cedar Rapids, St. Lawrence River.

with capacity requirements. The section and interior view of the Cedar Rapids generating station shown in Figs. 5 and 6 well illustrate the general design.*

Exciter Arrangement.

Within the last few years designers have reverted to the arrangement of direct connection of exciter generators to the power unit turbines. While this practice was long disapproved of, the electric voltage regulator as now developed has proven

* See General Electric Review, June, 1914, p. 533.



Drafting Room
Store Room
Switchboard Room
Generator Room
Gate and Screen Room
Elev. 538
Thrust Bearing
Brake
M.W.L. Elev. 529·50
Elev. 504
Elev. 394
Tailrace for Units 2,4,6,8 & 10
Elev. 394
Tailrace for Units 1,3,5,7,9 & 11
DEPARTMENT OF THE INTERIOR, CANADA.
DOMINION WATER POWER BRANCH.
TORONTO POWER COMPANY
SECTION OF POWER STATION,
NIAGARA FALLS.
To accompany paper "CANADIAN HYDRAULIC POWER DEVELOPMENT
INTERNATIONAL ENGINEERING CONGRESS
SAN FRANCISCO, 1915
4 0 4 8 12 16 20 24
SCALE OF FEET

Fig. 7.

its ability to counteract the combined effects of a varying exciter and generator speed when these are direct connected, and within reasonable limits of speed variation, the voltage curve of a power generator may be maintained commercially constant, regardless of load and variation of speed of the turbines. The advantage gained in generating-station and general-works design by the elimination of duplicated turbine-driven exciter sets is obvious; but it must be remembered that while power units may be self-excited by direct-connected exciters, in a station

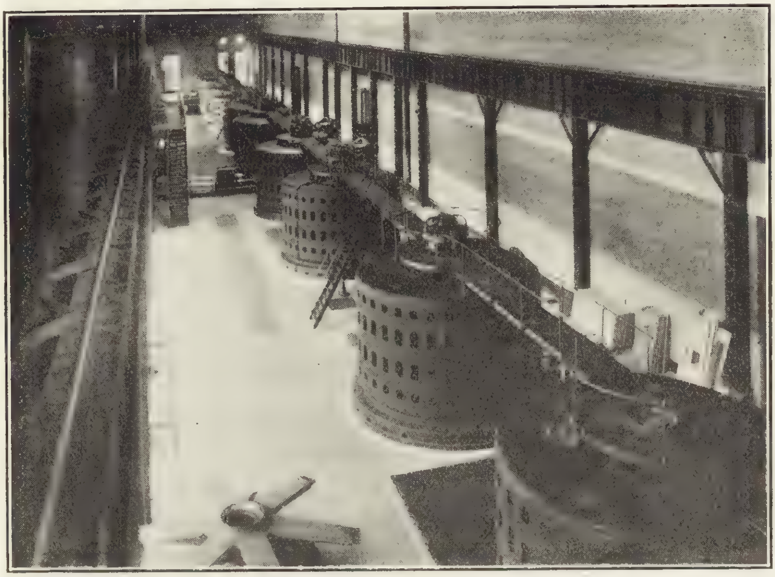


Fig. 8. Interior of Power Station, Toronto Power Company, Niagara Falls, Ontario.

of any magnitude the auxiliary equipment of the plant will demand a source of power available, preferably of direct current, independent of the main power generators. The application of direct-connected exciters in a large installation is well demonstrated in the installations of the Toronto Power Company's generating station, Figs. 7 and 8, where the generators, 10 in number, aggregating 100,000 horsepower, have all been equipped with direct-connected exciters; this plant is situated at Niagara Falls, Ontario, and transmits power to Toronto, approximately 80 miles distant.

Excitation systems now approach the elaborate, and possibly are the most finely adjusted and most fully automatic devices of power plant equipment. The supply of exciting power in the station of 100,000 horsepower calls for generating units of large dimensions, which in themselves compare with the entire capacities of many well known power plants.*

Turbine Speed Control.

Speed control of turbines has, in general, been required to meet the demand for constant voltage maintenance. The present possibilities of electrical voltage control are such that voltage need not be considered as the determining factor in turbine speed control; the maintenance of speed to obtain an approximate adherence to the specified electrical frequency instead becomes the important feature. The standardization of frequency to 25 and 60 cycles per second determines the standard speeds for which the turbines are adapted. Variation of frequency in commercial operating practice is not of such great consequence as the variation of unregulated voltage, and the demand for extremely quick turbine gate-closing mechanisms has, therefore, diminished where the voltage is controlled by electrical means.

The closing of turbine gates in two seconds from full open is now recognized as the standard performance. Regulation of speed during such a period, and until the hydraulic and mechanical factors become normal, is a problem to be solved entirely by proper designing for water supply to the turbine and the inertia storage in the moving parts. The fly wheel, whether separate or incorporated into the electrical generator, is an essential element of the regulation.

Water Passages.

The obtaining of high efficiency and good inherent regulation of turbines requires the greatest refinement in the construction of water passages throughout the whole system. The magnitude of the modern turbine demands large water passages which readily permit of their formation in concrete; the easy curves and smooth surfacing thus possible to obtain have been one of the greatest factors in the attaining of the high effic-

* See "Excitation and Voltage Control", Electric Journal, November, 1914, p. 612.

iencies. As an interesting example of the possibilities of such types of concreted structures, reference may be made to the Calgary Power Company's Kananaskis Falls plant on the Bow River, in the Rocky Mountain foothills in Alberta; the form, shown in position in Fig. 9, is approximately 24 feet in diameter, made in one complete structure in a convenient place and hoisted into its final position. The form is for one of the 6000 horsepower turbines which operate under 70 feet head at 164 revolutions per minute. Attention must also be drawn to the

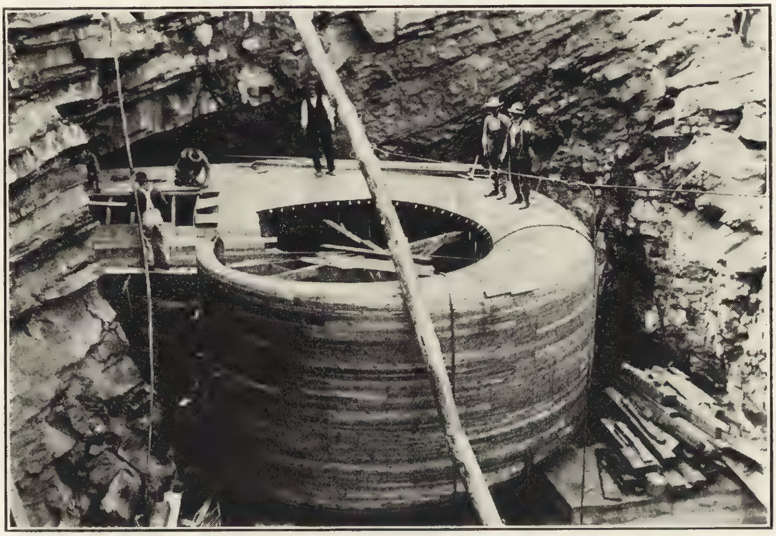


Fig. 9. Scroll Case Form in Place, Kananaskis Falls Development, Bow River, Alberta.

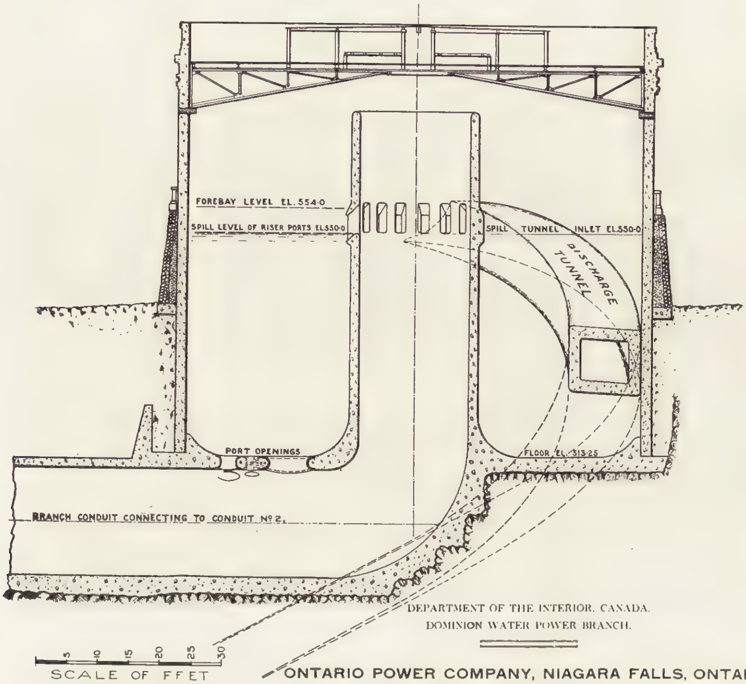
concrete-formed distributor and draft tube in the Cedar Rapids plant. (Fig. 5.)

Surge Tanks.*

The development of the surge tank for penstock and flume regulation has reached a most advanced stage in two recent installations. The first is that of the Ontario Hydro-Electric Power Commission's development at Eugenia Falls, Ontario, where the surge tanks are installed on the 4-foot penstocks leading to the power house, these tanks being placed on their re-

* See Proceedings, American Society of Mechanical Engineers, 1908; Proceedings, American Society of Civil Engineers, December, 1914.

spective pipes near the upper level of the 542-foot head. The second, and most notable example, is at the Ontario Power Company's plant at Niagara Falls, in which the surge tank terminates an 18-foot concrete conduit, described herein and shown in Fig. 11. The surge tank is illustrated in Fig. 10. The pressure water during surges is differentiated from the stored water



DEPARTMENT OF THE INTERIOR, CANADA.
DOMINION WATER POWER BRANCH.

ONTARIO POWER COMPANY, NIAGARA FALLS, ONTARIO
SECTION OF SURGE TANK, No. 2 CONDUIT.

To accompany paper "CANADIAN HYDRAULIC POWER DEVELOPMENT"

Fig. 10.

INTERNATIONAL ENGINEERING CONGRESS
SAN FRANCISCO 1915

by being carried up in the conduit riser or stand pipe and allowed to overflow through ports—or over the top of the riser if the surge is of sufficient magnitude—into the body of the enclosing surge tank; the stored water, as demanded, is drawn into the conduit only through the small ports in the floor which connect with the conduit. Surplus water and overflow water in the tank are discharged to the river by means of a tunnel whose upper

length, in the form of a helix conforming to the circular tank wall, is shown in the drawing; the spillway crest of the tunnel mouth is on a level with the riser port discharge level and four feet below headwater level at the intake forebay. The regulating action, in practice, has been excellent and promises to be a great aid in the practical development of many projected undertakings involving very long pipe lines.

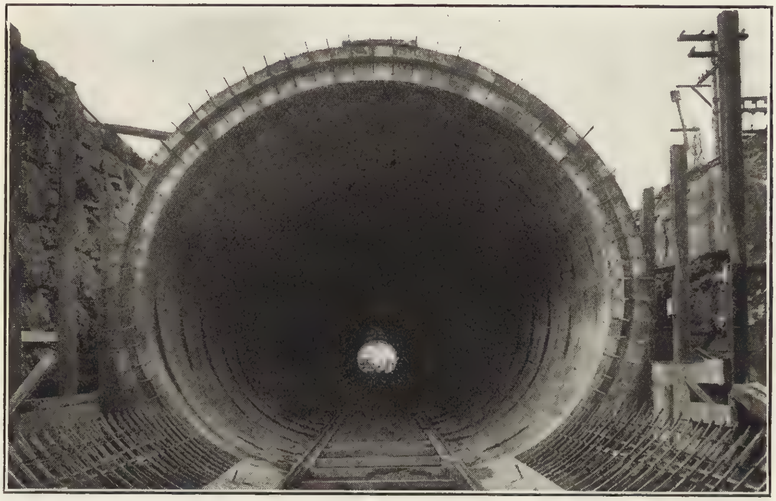


Fig. 11. Section of 18-ft. Concrete Conduit, Ontario Power Company, Niagara.

Water Conduits.

Several interesting examples of water conduits have been constructed during the last few years. The foremost, by virtue of its magnitude and its theory of design, is that of the Ontario Power Company at Niagara Falls, as illustrated in Figs. 11 and 12. This conduit has an equivalent diameter of 18 feet, but is of a distorted shape having a horizontal dimension of 19¼ feet and a vertical dimension of 16½ feet, adhering to the natural shape assumed by an elastic tube under its self-contained water and equivalent hydraulic head.*

* See "Hydro Static Chord", Proceedings American Society of Mechanical Engineers, May, 1910; "Stresses in Circular Pipes", The Canadian Engineer, November 13, 1913.

The conduit is of reinforced concrete, the bottom being formed first, as shown in the foreground of Figure 11, and the upper portion being formed by the collapsible movable forms carried on trucks, shown in Fig. 12; the outside forms are bolted through to the inner form through iron sleeves which are left in the finished structure and eventually plugged. The inner face was given a permanent hard smooth surface by troweling to minimise frictional losses. The conduit is 6,500 feet in length and has a rated capacity of 90,000 horsepower at maximum

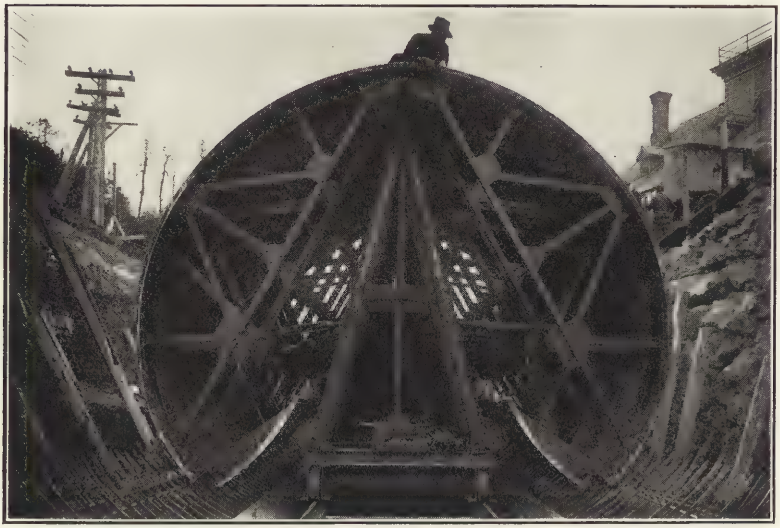


Fig. 12. Collapsible Steel Form for Conduit, Ontario Power Company, Niagara Falls.

velocity. This conduit is the second installed for this development, No. 1 being of steel and serving the first 80,000 horsepower of turbines; † No. 2 conduit serves the 90,000 horsepower of turbines since installed. In this generating plant of the Ontario Power Company there is 160,000 electrical horsepower output from 14 operating units, which makes the plant the largest individual hydro-electric generating plant in the world.

The wood-stave pipe as now built for water conduits must

† See "The Development of the Ontario Power Company", P. N. Nunn, A. I. E. E. Proceedings, June, 1905; and subsequent descriptions published by the O. P. Co.

DEPARTMENT OF THE INTERIOR, CANADA.
DOMINION WATER POWER BRANCH.

CITY OF PRINCE ALBERT, SASKATCHEWAN
SECTION OF DAM
AT LA COLLE FALLS DEVELOPMENT

To accompany paper "CANADIAN HYDRAULIC POWER DEVELOPMENT"

INTERNATIONAL ENGINEERING CONGRESS
SAN FRANCISCO, 1915.

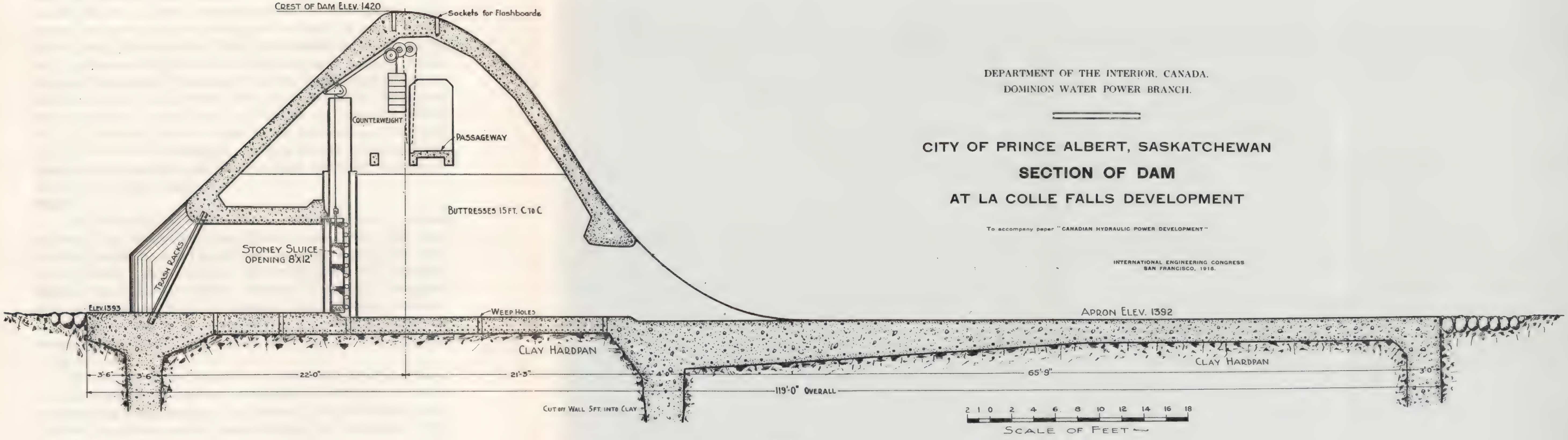


Fig. 13.

be considered a successful type of construction. These, in the round and open section made of British Columbia fir, are quite widely used in Canadian developments and are relied on to give long service, if properly constructed. The ease with which the wooden conduit materials, including prepared staves, banding irons, etc., may be transported and erected; the peculiar adaptability to the forming of curves as construction proceeds, and the freedom from penstock ice troubles when operating justify its use in a great many installations. The general experience has been that the rotting of the wood is not a serious factor, and if the conduit is full of water under a pressure sufficient to cause saturation of the staves, rotting is entirely absent. A most interesting development recently completed which has made extensive use of wood stave pipe of various dimensions and type is that of the Canadian Collieries on Vancouver Island, B. C.* The many novel devices for the conducting of water in this hydro-electric installation are well worthy of considerable study as representing, possibly, the most advanced practice in the use of wooden conduits.

Dams.

The concrete dam of the hollow buttress type is in almost universal use where any magnitude is involved. The most notable installations in Canada are, possibly, those of the Vancouver Island Power Company at Jordan River, on Vancouver Island; the Canadian Pacific Railway Company's irrigation dam on the Bow River, at Bassano near Calgary, Alberta, and the power dam at La Colle Falls on the North Saskatchewan River, built for the City of Prince Albert, Saskatchewan, (Fig. 13).

The Jordan River Dam is on a solid rock base and has a maximum height of 125 feet and length of 800 feet, of which 300 feet is spillway section. The Bassano Dam is of three parts, 720 feet of spillway section being of the hollow buttressed type, flanked on one side by 7000 feet of earth dam, and on the other by the concrete headworks structure. The spillway portion is built upon a 14-foot substratum of impervious clay lying on a thick bed of quicksand which comes to the surface some 3000 feet upstream; the buttresses are carried above the dam to form

* See Engineering News, October 23, 1913.

24 sluice openings fitted with stoney gates which are of sufficient capacity to discharge 100,000 cubic feet per second maximum flood water. The Prince Albert Dam is also built on a clay stratum with sand underlay; the most notable feature of this dam is the length of spill apron used, which is required for the maximum discharge of 180,000 cubic feet of water per second during flood period, the whole crest being used as a spillway and, in addition, this spill capacity is augmented by eleven stoney sluices discharging through the dam. The section shown in Fig. 13 illustrates the general arrangement of the Prince Albert Dam; the dam is 550 feet long extending between a concrete navigation lock and the hydraulic canal intake; the standard height is 29 feet above river bed; and the sectional width, including the apron, is 119 feet.

The best Canadian example of the hydraulic fill dam is the one built at Lake Coquitlam for the British Columbia Electric Railway Company, supplying the City of Vancouver and its vicinity in British Columbia. This latter dam is shown in section in Fig. 4 and its relation to the rest of this interesting plant may be judged from the general plan of the whole development. The scheme of construction of the Coquitlam Dam follows the now well established principles; the material, of a suitably graded nature, is sluiced into its final position from adjacent banks, and the sluicing flumes are so directed that the discharge deposits the heavier materials towards the slopes of the dam and the compacted sand, rock dust and clay are carried towards the centre, by the sluicing water, to form the impervious core. The Coquitlam Dam impounds the water in Coquitlam Lake, from which a tunnel, 12,650 feet long, through the intervening granite mountain discharges into Lake Buntzen. The initial power development, which is of 43,000 horsepower capacity, has its intake on Lake Buntzen with penstocks leading down to the No. 1 Power House (See Figs. 4 and 14). For No. 2 Power House a concrete-lined tunnel leads from an intake on Lake Buntzen to a surge tank constructed in the tunnel portal, from whence three penstocks are led down the cliff to the power house, making a head of 400 feet; the turbines in No. 2 plant, as are also those in No. 1 plant, are of the Pelton-Doble impulse type, each of the three units being of 14,000 horsepower capac-

ity under a head of 400 feet. The total installed capacity of the two power houses is 85,000 horsepower.

Relief Valves.

A very necessary adjunct to the long water-conduit is the relief valve for discharge of surplus water under the high pressure encountered on the closing of turbine gates and on the consequent surges. The characteristics of operation of relief valves vary over a wide range from spilling water con-

Fig. 14. No. 1 and No. 2 Plants, British Columbia Electric Railway Company, Burrard Inlet, British Columbia.

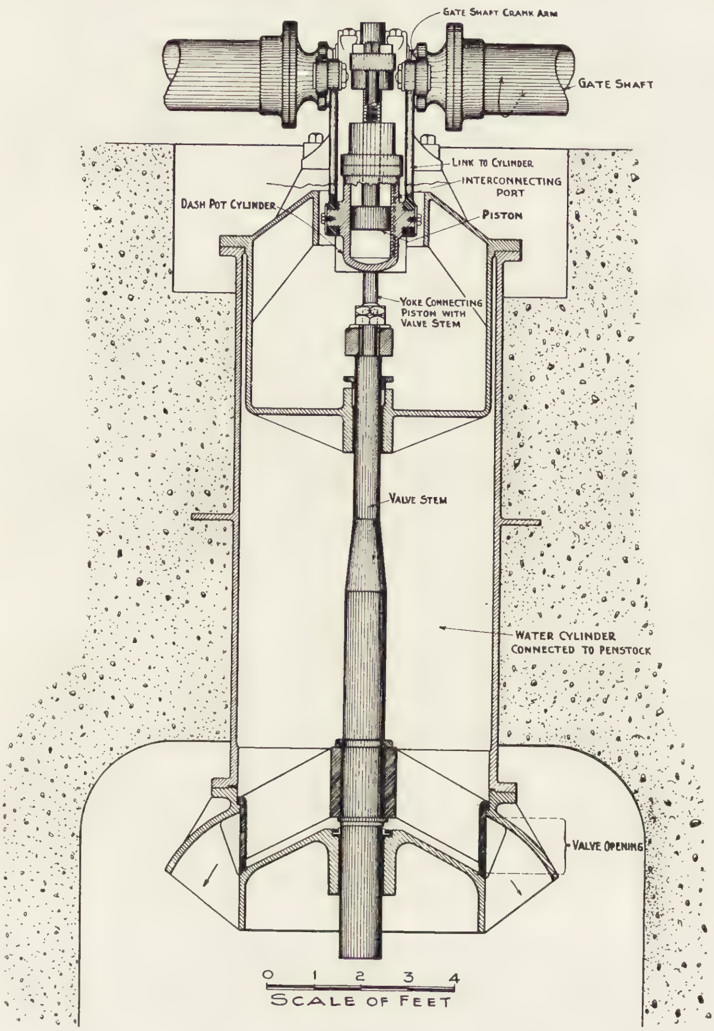
tinually to more or less ineffective opening after the building up of a very high excess pressure. The types which act synchronously with the closing of the gates, anticipating the pressure rise by the relative speed of gate closing, have reached a comparative perfection. The continuous spilling of water under normal operation is, in general, to be termed bad practice, and the high-pressure type may sometimes witness harm before the relief occurs. A bursting plate inserted on the penstock, which

by destruction under abnormal pressure permits of escape of water until the whole system is shut down and the repair men become active, has its uses in remote cases; its limited application is obvious.

Reference to Fig. 15* will illustrate the relief valve equipment employed on the 20,000 horsepower turbines at the generating plant of the Shawinigan Water & Power Company, which, to a great extent, is a result of this Company's experience with relief valves throughout the earlier portion of the development. This plant has now installed an aggregate of 147,000 horsepower in No. 1 and No. 2 Power Houses,† the latter having 100,000 horsepower capacity in five units; in addition, the Company sells water to customers for utilization in adjacent privately owned plants for the development of 43,000 horsepower. Penstocks approximately 600 feet long and 14 feet in diameter with a normal velocity of 8.5 feet per second under 145-foot head supply each of the five 20,000 horsepower turbines; each penstock divides into two feeders, one for each of the wheel cases of the respective turbines, and the relief valve is set in the crotch between the feeders and is arranged to discharge from the feeders into the draft tube. The mechanism of the relief valve may be readily understood from the drawing. The operating shaft is connected to the relief-valve dash-pot by levers and links, and the dash-pot piston to the relief-valve spindle by yokes and trunnions. The dash-pot is oil filled and the ends of the dash-pot are interconnected by two by-passes cored in the casting, one by-pass containing a needle valve and the other a spring check-valve operating in only one direction. When the turbine gates are closing, the dash-pot moves up, being operated by the gate-shaft lever; and should the speed of this movement be such that the oil underneath the dash-pot piston will by-pass through the needle valve to the other side of the piston without building up sufficient pressure to overcome the weight of the relief valve, then the relief valve remains closed; while if the movement occurs at such a sufficient rate that pressure is built up to overcome the weight of the relief valve, then the valve is opened and tends to close again

* By courtesy of The I. P. Morris Company, Philadelphia.

† See Electrical World, May 4, 1912.



DEPARTMENT OF THE INTERIOR, CANADA.
DOMINION WATER POWER BRANCH

SHAWINIGAN WATER AND POWER COMPANY

SECTION OF RELIEF VALVE,

NO. 2 STATION.

To accompany paper "CANADIAN HYDRAULIC POWER DEVELOPMENT"

Fig. 15.

INTERNATIONAL ENGINEERING CONGRESS
SAN FRANCISCO, 1915

by return flow of the oil through the check valve. Adjustment is made by manipulation of the needle valve.

In the impulse waterwheel installation at Coquitlam, previously described herein, relief valves operated by the governor are installed. The impelling nozzles are of the needle type; the relief needle-nozzle is similar to the power nozzle and is connected to the governor gear, so that the relief valve tends to open, through the intermediary of an oil pressure dash-pot, when the impelling nozzle closes. *

Protection Against Flooding.

Several aggravated cases of power house flooding due to failure of hydraulic equipment or excessive rise of tail water, with consequent shutting down of plant and the destruction of electrical apparatus, have had a marked effect on design of stations. Isolation of hydraulic machinery has been obtained in the Shawinigan No. 2 station by a wall separating hydraulic and electric bays, the wall being carried to a sufficient height to accommodate the maximum unimpeded flow through one of the 14-foot penstocks, if accidentally discharged into the station; the water finding a vent through the doors and windows, etc. In some stations all exposed doors and windows are fitted with stop log seats—a barricade being built up to protect against outside flood in case of abnormal water conditions. In many instances power houses can be economically placed only in positions which at very infrequent intervals may be subjected to flood conditions, and while available sources of information in regard to maximum water-levels, historically speaking, indicate the safety of the situation, the introduction of a new element in the river courses, in the form of power works, may greatly affect the normal characteristics of river behaviour. Precautions against the remote possibilities of excessive flood are so easily taken that it is advisable to make all possible provision.

Log Runs and Fish Ladders.

Log runs and fish ladders are peculiar to a great many Canadian developments. Most of the northern rivers are the arteries which tap the timber limits, and conveniences in logging through the obstructions created by power works are

* See General Electric Review, p. 549, June, 1914.

essential. Lumbering is one of Canada's principal industries, and from pioneer days has been controlled and protected by very efficient legislation.

A log run is approached on the upper level by an ample forebay, which narrows down to an intake approximating to a V-shaped trough into which the logs can be floated and carried down by a water stream until discharged into the tail race. Interesting diversions from the usual practice of timber-constructed log runs are that of the High Falls Dam, on the Lievre River, in the Province of Quebec*, in which a reinforced concrete V-section trough is used (See Fig. 16)†; and that of the contemplated Grand Falls development in New Brunswick, which is now under way to supply the City of St. John. In this latter plant, due to adverse topographical features, a tunnel is planned to lead from the forebay to the lower river and will be utilized to carry logs only, the necessary water being admitted at the upper portal of the tunnel. The season during which the logs are moving is usually the spring-flood period, when a surplus of water is available for manipulation of logs in transit.

Fish ladders and fish-ways are demanded at the discretion of the Minister of Fisheries, in Canada, to be installed in connection with power works which otherwise obstruct the fish channels. Such fish ladders generally take the form of a series of pools built of wooden boxes, the lift on each being about 10 inches and the partition bulkhead between the compartments having a one-foot square opening through which, in addition to the spill over the tops of the bulkheads, the water passes from the upper level to the lower.

The foregoing subjects, which have appeared to the writer as comprising the outstanding features of Canadian hydraulic power developments from the hydraulic engineer's standpoint, have in their discussion permitted the description of several of the Canadian plants of greater or less magnitude. Canada is well known as having limitless water powers and practically all of those lying within economic range of markets or so situated as to be favourable for creation of industry have been

* See Canadian Engineer, January 7, 1915.

† By courtesy of John B. McCrae, Ottawa, Consulting Engineer.

Fig. 16. Concrete Log Chute, High Falls, Quebec.

developed in some manner, and at present it is estimated that over 1,700,000 horsepower is developed as hydraulic power, the greater portion of which is converted into electrical energy. In

the near future, several of the schemes of enormous size now contemplated, and with power units of capacity far in excess of any now developed, will doubtless be realized, and in less than a decade even more notable progress may be recorded than that herein described.

ICE CONDITIONS.

As has been before stated, ice conditions have been a serious factor against the continuous operation of hydraulic plants.

The ice problem is one which has engaged the hydraulic engineer throughout the whole history of development of Canadian water power plants. The low temperatures of winter are responsible for the diminution of run-off, the reduction of river areas and the entire freezing up of small streams. The retention of the greater portion of the winter's precipitation leads to spring flood flows of magnitude many times greater than the normal discharge, while the breaking up of surface ice in spring readily becomes a menace to be guarded against in protecting constructed works. The accommodating to small winter water-supply is an economic problem, and the controlling of floating ice and of flood water is a problem of routine operation. The great difficulties, however, in the handling of water under winter conditions are due to the slight changes in the temperature of the water, when varying but a small fraction of a degree about the freezing point. It must be realized that the temperature of the water, even in the most severe weather, does not appreciably vary from the freezing point; indeed, it is only by the most delicate thermometers that the variation can be detected, but within a small range of temperature the most distracting troubles may arise.

There are three kinds of ice which are generally recognized: First, surface ice or sheet ice, which forms on still or comparatively still water; second, anchor ice which forms and grows on the beds of rivers which are not protected with surface ice; and third, frazil ice, which forms in the agitated water of rapids, falls and high velocity channels and accumulates in great masses in adjacent undisturbed water.

Surface ice may or may not be harmful. The chief trouble is experienced by the total freezing up of small streams and the diminution of the cross-sectional area of the rivers. The ice floes and broken sections when loosed in spring are frequently troublesome through the forming of jams in the water channels, thus cutting off water supply or raising the tail-water to an extent sometimes disastrous. Further, it must be realized that surface ice in an open stream converts the waterway into a closed channel, and by the friction imposed by the surface covering transfers the cross-sectional area of maximum velocity to a greater or less depth, according to conditions. The velocity factors in stream gauging under such circumstances must, of course, be correspondingly changed.

Anchor ice most often causes trouble by its rising in masses from the river bottom; even rising and carrying stones and boulders of considerable size which have been embedded in the mass. While anchor ice is first formed by the radiation of heat on a cold, clear night, this will probably be accompanied by the forming of frazil, the anchor ice becoming the nucleus for the accumulation; such active masses are to be included among the operator's greatest trials.

Frazil ice is the most troublesome, but it is only to be expected where the air temperatures are hovering slightly below the freezing point. This is a condition to be met at the beginning and end of the winter season or during a changeable period, and after a short experience with it, its vagaries may be readily anticipated and the necessary precautions taken. The ice crystals formed by exposure to the cold atmosphere grow rapidly and adhere to one another to form lumps and spongy masses, attaching to every cold body they encounter; racks or screens, penstocks, turbines and all essential parts of water-power equipment are readily affected by enormous accumulations capable of completely closing down the plant. The great majority of power plants have suffered; the modern plant, however, has become more immune from the effects, now that a full understanding of the problem is possible.

In selecting the site for power works on a river one must bear in mind the chances of ice troubles. Naturally, it is preferable to have large still-water pondage immediately above the

water intakes; such a provision assures surface ice, which will obviate the formation of frazil and anchor ice adjacent to the power works. Unruffled water in the river supply for several miles above the pondage may be expected to reasonably free the lower waters of frazil; this condition is usually readily obtained, as in the damming of the river the adjacent rapids or falls are drowned out and the consequent head taken advantage of. The tail race and lower river must be viewed from the standpoint of ice discharge and the river course eased sufficiently to preclude any possibility of ice jams. Floating ice may be discharged from the forebay by booms arranged to deflect the ice to ice overflows and runways, which may carry it to the tail race. Ice which may be carried under the boom or screen house curtain so as to accumulate in front of the intake racks has generally to be poled out to the main ice overflow or to a separate runway adjacent to the screens.

It has been found by experience that the source of trouble from frazil ice is its great adhering power to cold bodies in the water. Iron screen racks are much affected when, in the presence of frazil, their temperature is but a fraction of a degree below the freezing point. The precautions are obvious. The submerging of iron racks below the surface will insure their being at the same temperature as the water and they will not act as conductors of the cold from the air; the top screen section which may extend above the water level may be of wood, which will act as a comparative insulator to the transfer of cold. Iron racks rising above the waterline may be fitted with a housing containing heat supplied by electricity or steam, so that the iron will conduct a small amount of heat throughout its length; the wider application of this is the screen house which is sheltered completely from outside air and may or may not be heated.

Iron penstocks, and turbine cases, have been known to be completely blocked by frazil ice, due to the colder temperature of the iron. The housing in of all water-carrying equipment is essential where frazil is encountered. The covering of surge tanks to protect against excessive freezing where the surface water is undisturbed for a sufficient period, such as may occur with a continued steady load, is essential.

The problem of housing of penstocks has evolved several practical and economic methods, when burying them is not possible nor desirable. The most common and possibly the cheapest, arrangement is by means of a continuous wooden sheeting, having two vertical sides and a sloping or peaked roof, all on a simple wooden framing. A better arrangement, and undoubtedly a more desirable method, is by the application of metal lath or wire netting on metal or wooden framing plastered over by cement gun or by hand; the same scheme of covering may be used on surge tanks; these, however, are generally of such magnitude that it is preferable to include them in the architectural featuring, along with the power-plant buildings.

The necessary exposure of gates, sluices, stop-log guides and seats, racks, etc., has required, in several cases, the installation of steam-heating plants supplying permanently placed steam piping for maintaining freely working equipment, and in the notable case of the Shawinigan plant, heated air is blown onto the protruding racks and onto the incoming water in the screen house.

DISCUSSION

Mr. Mitchell. **Mr. P. H. Mitchell,**† Assoc. A. I. E. E., in opening the discussion on his brother's paper, said that the method of control of potential power sites in Canada seems to be more satisfactory than the control in this country, as brought out by the statement in Mr. Galloway's paper and the subsequent discussion.

The attitude of the Dominion itself is fatherly and tends to advance as much as possible the establishment of power plants.

He called attention to the concrete conduit referred to in the paper as being interesting, having cost $1,000,000 per mile, but the construction adhered closely to the original estimates, and the expenditure was entirely justified.

He asked for information from those who had had experience in this line, as to what effect corrosion has upon water wheels, and whether their efficiency decreases as time goes on. This question is continually coming up in Canada, where there are a great number of single-runner turbines in operation. The idea is commonly held that, due to corrosion, the efficiency would run down very rapidly as time goes on.

Mr. Doble. **Mr. W. A. Doble,*** M. Am. Soc. C. E., said, in regard to efficiency maintenance, that it was governed by two things: First, by the character of the design of the prime mover, and second, by the character of the water used.

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† Cons. Engr., Toronto, Ontario, Canada.

* Ch. Engr., Pelton Water Wheel Co., San Francisco, Calif.

Mr. Doble.

They had had turbines in service for several years and after this period, when tested for efficiency, they did not show as great a decrease in efficiency as one might assume. The serious problem is the grit or silt in the water. If serious eddy action takes place, erosion follows, where the water contains any grit. Efficiency will fall off due to leakage and wear in clearance rings; the more leakage, the more cutting there will be, and hence, as time goes on, the efficiency will decrease rapidly. The individual characteristics of each installation will alone determine how its efficiency will fall off with time.

Paper No. 146

HYDRAULIC POWER DEVELOPMENT AND USE.

By

J. D. GALLOWAY, M. Am. Soc. C. E.
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INTRODUCTORY.

The purpose of this paper is to set forth the general engineering features of hydraulic power development and the use of the same for the generation of electric energy. While hydraulic power is often developed for direct application to the consuming machine, such, for instance, as stamp mills or manufacturing establishments, such practice long ago became standardized. The principal interest that attaches to the subject, at present, is in the development of hydro-electric plants. By limitation of the program, only general reference will be made to the design of water wheels and to the electrical parts of such plants, such being treated in detail in other papers of the Congress. A brief reference to the history of the development will be made, in order to form a background for setting forth the present state of the art. The paper is also largely limited to American practice, due principally to lack of familiarity with European work and also to lack of time to make the necessary investigation.

A natural division separates modern hydro-electric plants into two types: first, low head plants, and, second, medium and high head plants. In the first, the water is taken directly from the stream in short penstocks and used in large quantities, while in medium and high head plants the water is carried some distance in smaller quantities, in various designs of conduits, to a point high above the power station, and delivered thence in pressure pipes. A corresponding, though not as well defined, division exists in the type of water motor; the low head requiring the turbine and the medium and high head

either the impulse wheel or the turbine. It is natural that these two divisions overlap, especially in the type of water motor used. As used herein, the word "head" refers to the vertical height of the column of water above the water wheel.

HISTORICAL.

It is unnecessary to review the history of the turbine, but a few notes on the development of the impulse wheel may be of interest. The idea of developing power from a wheel turned by the impact of a jet of water, was clear to Italian, French and English writers and investigators during the past three hundred years. The first patent embodying the principle was applied for in America by Atkins, in 1853. Independently of this, the miners of California, in 1850-1860, had developed a crude type of impulse wheel to drive their mills. The first wheels were made with flat blocks as buckets, but in 1866 there was installed in the Gwin mine a wheel with buckets that reversed the direction of the jet. In 1870, S. N. Knight brought out a wheel with buckets in which the proper discharge of the water was provided for. In 1873, Nicholas J. Coleman secured a patent for a bucket with a dividing wedge for splitting the stream, but the merit of this device was not then appreciated. In 1874, Joseph Moore, of San Francisco, built buckets with a dividing wedge. L. A. Pelton, between 1878 and 1880, made experiments and investigations which resulted in the Pelton form of bucket with a dividing wedge, and the impulse wheel takes the name of the Pelton wheel from his work. A number of other men were also associated in the perfecting of the wheel. There is, of course, some dispute regarding the priority in this work.

The use of the impulse wheel was very general in the West, and the installation of these wheels was soon made upon definite lines. The first recorded use of an impulse wheel to drive an electric generator was at Ames, Colorado, where the Telluride Power Co. installed 2-150 kw. single-phase generators operated by Pelton wheels under 500 ft. head, in 1890. Another early installation was at Virginia City, Nevada. This town is situated on a mountain side, and the Sutro tunnel, some five miles long, had been driven in to drain the mines, at a level of about

1,700 feet (518 m.) below the general surface. To provide more power for the mill, a generating plant was installed in the Chollar shaft, consisting of six 40-inch (101.6 cm.) Pelton wheels driven by water under 1,680 feet (512 m.) head and operating six 100-horsepower, constant-current Brush dynamos, running at a speed of 900 r. p. m. The line was carried up the shaft to the mill, about one mile. This plant was installed in 1891.

One of the first plants to transmit power any distance, if not the first, was the single-phase transmission installed between Oregon City and Portland, Oregon, in 1889, a distance of 13 miles (21 km.). The generators were operated by turbines. At Pomona, California, a single-phase plant was in operation early in 1891, the generators being driven by impulse wheels and the current being transmitted to San Bernardino, 28¾ miles (46.2 km.), at 10,000 volts pressure. Other single-phase plants installed about that time were those at Telluride, Colorado, with a fifteen-mile (22 km.) transmission. A single-phase plant at Bodie, California, was placed in operation in 1893, using water under 350 feet head on an impulse wheel to operate a 120 kw. single-phase generator. Current was transmitted 12½ miles, at a generator voltage of 3500.

The first three-phase transmission was the experimental line from Lauffen to Frankfort, Germany, built in 1891. In America there were two plants under construction, Mill Creek No. 1, at Redlands, California, transmitting current 7½ miles (12 km.), going into operation September 7, 1893; and the Guadalajara, Mexico, plant, being operated the same year. At the same time, plans were being formulated for the first plant at Niagara Falls, and two plants in Italy,—Tivoli to Rome and the river Gorzente to Genoa,—were operating on the Ganz system, with transmission lines each eighteen miles (29 km.) long.

The marked success of all these first plants led to a rapid development, especially in America. Table 1 of the Appendix, which is necessarily incomplete, gives some information as to early plants.

The growth in size of the generators is an indication of the rapid development of the art. The 3730-kw. generators of the

first Niagara plant, projected in 1893 and first placed in service in October, 1895, remained for some time the largest single units, not being exceeded until 1904, by the 5000-kw. unit at de Sabla. In 1905 a 7500-kw. unit was placed in operation at Niagara Falls. The 10,000-kw. units at Las Plumas, Cal., installed in 1908, were the first example of a size that remained standard for a number of years, except possibly some with a more liberal rating of the generator but of the same nominal power, though much larger units have been designed. In 1913, the Big Creek No. 1 generators, of 17,500 kv-a., were placed in operation and these units are today the largest size in water power plants.

There was an ample precedent in California for the use of high heads in hydro-electric plants, as Pelton wheels were operating under heads up to five hundred feet in mills and mines. The use of sheet iron pipe in the mines commenced in 1853. The Cherokee "inverted siphon" in Butte County, 30 inches (76.2 cm.) in diameter, under a maximum head of 1000 feet (305 m.) and 14,000 feet (4270 m.) long, was laid in 1869. In 1872-3, Mr. Hermann Schussler built the pressure pipe of the Virginia City water-works across the head of Washoe Valley. It was 12-inch (30.5 cm.) diameter, with a maximum head of 1720 feet (525 m.), and a length of over seven miles (11.2 km.). The head of 1680 feet (512 m.) at the Chollar mine, in 1891, has been mentioned. The first of the regular power plants to use a high head was that of the San Joaquin Light and Power Company, where, at Plant No. 1, in 1895-6, a pipe under 1411 feet (431 m.) pressure was installed. At present the highest head in use is in Switzerland, where water is used under 5200 feet (1585 m.) pressure.

MEDIUM AND HIGH HEAD PLANTS.

For convenience, plants with heads up to 200 feet (61 m.) are referred to as those with a low head; those from 200 feet (61 m.) to 750 feet (228 m.), as medium head plants; and those above 750 feet (228 m.), as high head plants. For medium and high head plants the equipment may consist of storage reservoirs; a diverting dam on the stream; a conduit which may be made up of tunnels, flumes, open canals or pipes, distinguished

from the penstock by following close to the hydraulic grade line; a regulating reservoir or surge chamber at the upper end of the penstock pipes; the penstock pipes with auxiliaries, such as gate and air valves; the water motor, which may be a turbine with relief valves or an impulse water wheel with deflecting nozzle, by-pass or jet deflector; the electric generator, with an exciter and the other equipment of transformers, switchboard, low and high tension switches, bus bars, lightning arresters, oil pressure pumps, etc. The low head plant is usually without the storage reservoir, and since the water is generally taken directly from the stream or a forebay, the conduit and the regulating reservoir are eliminated, while the penstocks are short pipes.

Tables Nos. 2 and 3 of the Appendix give the data of some of the high and medium head plants of recent construction and indicate the present stage of development.

Storage Reservoirs.

Nothing in this subject differs from ordinary construction of dams, but a few notes of recent work on power plants are of interest. The early miners of California originated the rock-fill dam, of which the Bowman dam on the South Fork of the Yuba River is a good example. It is 100 feet (30.5 m.) high, 425 feet (129.5 m.) long on the crest, retains 930,000,000 cu. ft. (26,348,000 cu. m.) of water, and was built in 1872-6. It is faced with three layers of planking at the bottom, two in the central height, and one in the upper portion.

The dams at Meadow Lake and Bear River, of the Standard Electric Company system, are each about 75 feet (23 m.) high and about 1000 feet (305 m.) long on the crest. Two dams on Bishop Creek, California, on the system of the Southern Sierras Power Company, are of this type, each about 75 feet (23 m.) high, all faced with timber. The Sierra & San Francisco Power Company dam at Relief Valley on the Stanislaus, built 1906-8, is 140 feet (42.7 m.) high, and is faced with concrete. The same company is building another rock-fill storage dam, on the South Fork, which will be 145 feet (44.2 m.) high, 625 feet (191 m.) on the crest, and faced with concrete. The Morena dam, near San Diego, completed in 1911, is a good example of this type of dam. It is about 200 feet (61 m.) high

above the stream bed, and is faced with concrete a part of the height. The essential feature of this type is an impervious face on the dam next to the water. In some dams this has been made of layers of planking, generally three inches (7.62 cm.) thick. Later and higher dams have been faced with reinforced concrete. The first dam where concrete was used was at Relief, which has a face 36 inches (91.4 cm.) thick at the bottom, tapering to 9 inches (22.9 cm.) thickness at the top. These dams have a slope on the water face of about ¾ to 1, and on the downstream face the natural slope of rock, varying from 1.3 to 1.5 to 1. The upstream portion of the dam is made with derrick laid rock, and the downstream portion of loose rock. The rock-fill portion of the Crane Valley dam, of the San Joaquin Light & Power Co., was built with a central core wall of concrete, 148 feet (45.2 m.) high.

Another type of storage dam of recent use is the masonry arch, where dependence is placed upon arch action for stability. The Lake Spaulding dam, of the Pacific Gas & Electric Corporation, built in 1913, is of this form. It is 225 feet (68.5 m.) high and designed for an ultimate height of 305 feet (93 m.). The radius is a variable one, depending upon the elevation. The dam was built of concrete. Another dam of the same type was built in 1913-14 for the Alaska Gastineau Mining Company, on Salmon Creek near Juneau, Alaska. It is 164 feet (50 m.) high, and built of concrete. Dam No. 1 of the Big Creek plant of the Pacific Light & Power Co., California, is arched in plan but has a gravity section. It is 139.5 feet (42.5 m.) high and is built of concrete.

Hydraulic fill dams have been built for storage reservoirs, notably at Lake Francis on the Colgate plant, California; at Necaxa, Mexico, where the dam is 180 feet (55 m.) high, 1276 feet (388 m.) on the crest, and a base width of 950 feet (290 m.); and at Big Meadows, on the Great Western Power Company's system.

Diverting Dams.

The earlier practice was to build the diverting dams of timber cribs, sheathed with plank and filled with rock. The Sand Bar Flat dam, of the Sierra & San Francisco Power Company, is an example of this type of dam. As a rule the con-

struction of the diverting dam is of rubble masonry or of concrete of an ogee section, designed to pass the river floods. For a low head plant, the highest dam yet constructed is that of the Washington Water Power Company at Long Lake, where a concrete dam 200 feet (61 m.) high above foundations and 400 feet (122 m.) long, was constructed during 1911-13. At some diverting dams, where the penstock leads directly from the pond, the head is raised by flashboards. At Folsom, a sys-

Dam and Headgates of the Sierra & San Francisco Power Co., Stanislaus Plant, Sand Bar Flat, Calif.

tem of flashboards six feet (1.82 m.) high, raised by hydraulic cylinders and pistons, was installed, but, as they were of timber, these flashboards were removed when worn out. At Las Plumas, 10-foot (3 m.) flashboards, of timber needles resting on timber frames, were installed during two summers. At Long Lake the plan is to install roller type flashboards after the pattern of those used in Europe.

Water from the river is usually taken into a masonry chamber through screens in openings which can be closed by

gates. The face of the receiving basin is generally placed nearly parallel with the direction of the flow of the stream. Below the entrance chamber, a settling basin is built, with gates to discharge the accumulation of sediment into the river.

Ditch of 470 cu. ft. per sec. Capacity. Sierra & San Francisco Power Co., Stanislaus River, Calif.

The Conduit.

The earlier plants in California were built where old mining ditches were available, or in accordance with the practice with the miners, who made use of open canals in earth, timber flumes, pressure pipes across depressions, and tunnels. The

Flume of 470 cu. ft. per sec. Capacity. Sierra & San Francisco Power Co., Stanislaus River, Calif.

Flume of 470 cu. ft. per sec. Capacity. Sierra & San Francisco Power Co., Stanislaus River, Calif.

Typical Wood Stave Pipe. 4 ft. (1220 mm.) pipe of the Oregon-Washington Power Co., 28,000 ft. (8550 m.) long.

Typical Wood Stave Pipe. 8 ft. (2440 mm.) diam. Entiat Light & Power Co., Washington. Maximum head, 85 ft. (25.9 m.).

conduit of the de Sabla plant is the upper portion of the old ditch and flume of the Cherokee Mining Company; and of the plant at Electra, the conduit is that which was built to supply the mines of Amador County with water.

Necessarily, the conduit of each power plant is a problem to be solved in accordance with the particular requirements and the means at hand. In the West, and where timber is abundant, the timber flume has been used in the past and will be used in the future, for, while it has a short life, it is often vitally necessary to reduce first costs to a minimum. The steel flume, made with a semi-circular body of galvanized sheet steel supported on a timber frame, has been used on irrigation systems for a number of years, but as yet has not been applied to power plants. The life of such construction has not been determined by actual practice. Flumes made of concrete have been used in a few cases, but the cost at present affords one of the main reasons for its not being employed more extensively. The Loch Leven plant in Scotland, with 18,000 feet of concrete flume, and the plant of the Arizona Power Company, with 12,000 feet of the same construction, are the best examples of this type of conduit. Concrete pipe has been used in one plant in America,—that at Boulder, Colorado, where there are 12 miles (19.3 km.) of 36-inch (915 mm.) pipe; but this is the only example of a large installation of this character. Some use has been made of concrete pipe in Norway. Wood stave pipe, under pressure up to 200 feet head and in large diameters, has been used extensively. California redwood has been employed in a number of places, as it has a long life, but Douglas fir is also extensively used. The pressure of the water upon the wood keeps it saturated and decay is slow. Such pipes, used as conduits without pressure, are liable to quick decay, especially if buried in the ground. Tunnels under pressure, or simply acting as open flow conduits, are generally lined with concrete. In one case, at the Bull Run plant of the Portland Railway, Light & Power Company, the water was carried by a flume in the tunnel. Large steel pipe has also been used in a number of installations, either as the entire conduit, or in crossing side streams and depressions. The 18-foot (5.5 m.) pipe, 6300 feet (1900 m.), of the Ontario Power Company, and

the 15½-foot (4.72 m.) pipe, 2350 feet (685 m.) long, of the Rainbow Falls, Montana, plant, are examples of the largest pipe constructed. The open canal in earth is probably the most general form of conduit, but the tendency at present is to line the canals with concrete, thus either reducing the section or increasing the amount of water carried, on account of reduced friction.

Any one conduit usually includes several of the various types mentioned above. Table No. 4 of the Appendix, which does not aim to include all plants, is illustrative of the methods used by various engineers and can be taken as indicative of present practice. Where no data are given of any one type of construction, it is indicated that such was not used. The tendency is to eliminate all types that are not permanent in their nature.

Regulating Reservoirs and Surge Tanks.

In the earlier plants the influence of the load factor was not appreciated, and many were built without regulating reservoirs. Obviously, the peak capacity of a plant without a regulating reservoir is limited to the flow of the conduit, and at times of off peak load, water is wasted. The regulating reservoir performs all of the functions of a surge tank of large size, and, in addition, it regulates the uniform flow of the conduit, allowing large drafts of water over the peak and storing up water at times of minimum demand. This latter function the surge tank does not perform, except to a limited degree. In medium head plants, a regulating reservoir must be relatively quite large, and in cases where the conduit is a pressure pipe throughout its length, the pondage on the stream must supply the functions of such a reservoir. Occasionally, high head plants have the entire conduit under pressure, and the diverting reservoir on the stream or a storage reservoir performs the functions of a regulating reservoir.

Examples of high head plants, where the regulating reservoir is placed at the lower end of a free flowing conduit, are as follows, all dams being of earth.

Regulating Reservoirs.

	Plant	Capacity in Cu. Ft.	Capacity in Cubic Meters
(1)	De Sabla, Cal.	12,000,000	340,000
(2)	Drum, Cal.	19,300,000	546,000
(3)	Stanislaus, Cal.	14,000,000	396,000
(4)	San Joaquin No. 1, Cal.	18,000,000	510,000
(5)	Boulder, Colorado	19,000,000	538,000
(6)	Bull Run, Oregon	91,500,000	2,585,000

In such plants, the capacity of the reservoir will operate the plants over an ordinary daily load curve of 40 per cent. load factor, or higher.

In plants where the conduit line is under pressure, taking water from a reservoir or stream, the long line of pipe must be provided with a surge chamber near the junction of the conduit and penstock pipes, for the double purpose of receiving water from the conduit at time of suddenly rejected load and of providing water immediately when a load is suddenly applied to the wheels. Such chambers can be designed to give practically dead beat movement to the water in the conduit. The following partial list of surge tanks or chambers will illustrate modern methods.

Great Northern Power Co. At the end of a pressure conduit about 8800 feet (2680 m.) long, a 6-foot (1.83 m.) standpipe 165 feet (50.3 m.) high, leading vertically to a steel tank 30 feet (9.15 m.) in diameter and 70 feet (21.3 m.) high, placed about 500 feet (152 m.) from the power house. A number of plants have surge chambers of this type.

Pacific Light & Power Corporation. Big Creek Plant No. 1, California.—At the end of a conduit 10,360 feet (3160 m.) long, a standpipe 24 inches (95 mm.) in diameter, 425 feet (130 m.) long, enlarged at the upper end to a chamber 36 inches (146 mm.) in diameter, and 25 feet (10.7 m.) high.

Big Creek Plant No. 2.—At the end of a tunnel 21,300 feet (6500 m.) long, an excavation in the mountain, lined with concrete, 30 feet (9.15 m.) diameter and 120 feet (36.6 m.) high.

Pacific Coast Power Co. White River Plant, Washington.—At the end of a tunnel 2850 feet (869 m.) long, an excavation in the mountain, lined with concrete, 30 feet (9.15 m.) diameter and 75 feet (22.9 m.) high.

Northwestern Electric Co. Condit Plant, White Salmon River, Wash.—At the end of 5070 feet (1545 m.) of wood stave pipe, a concrete lined excavation 41 feet (12.5 m.) high and 40 feet (12.9 m.) diameter.

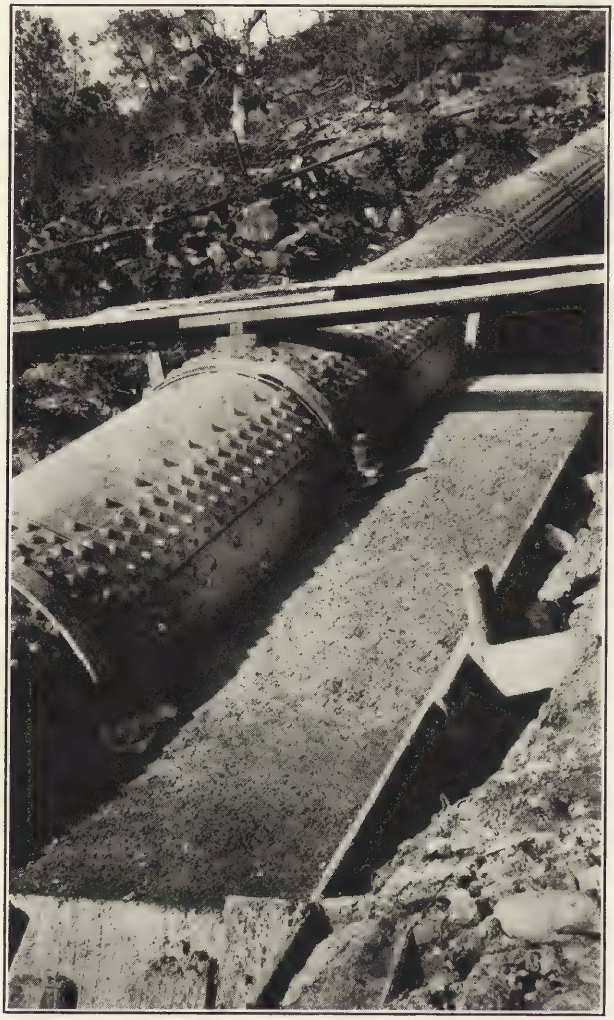
Los Angeles Aqueduct. San Francisquito Power Station No. 1.—At the end of a tunnel 7½ miles (12 km.) long. A concrete lined chamber partly in excavation. The lower part is an inverted truncated cone, 30 feet (9.15 m.) diameter at the lower end, 100 feet (30.5 m.) diameter at the upper end, and 85.5 feet (26.1 m.) high. The upper part is a cylindrical continuation from the base of the cone, 100 feet (30.5 m.) diameter and 44 feet (13.4 m.) high, making the total height above the top of the tunnel 129.5 feet (39.5 m.).

Georgia Railway & Power Co. Tallulah Falls.—At the lower end of a tunnel 6665 feet (2030 m.) long. A reinforced concrete lined chamber partly in excavation, of rectangular section, 30 feet (9.15 m.) wide, 71 feet (21.6 m.) long and 93 feet (28.4 m.) high.

Salmon River, New York. At the end of a conduit 9625 feet (2940 m.) long, a steel tank supported on a steel tower. The tank is cylindrical, 50 feet (15.3 m.) diameter, and 80 feet (24.4 m.) high, with a capacity of 187,000 cubic feet (5,300 cu. m.). The top is 205 feet (22.5 m.) above the ground and a 12-foot (3.64 m.) diameter riser connects to the penstock. The top of the riser is closed, but it is provided with ports so that a surge causing a rise of water is dampened, a portion of the water flowing up to the top of the surge chamber through a pipe of small diameter.

Penstocks.

In the earlier work in California, some cast iron pipe was used in penstocks, notably at Colgate and a portion of the first two pipes at Electra. At the present time all penstocks are built of either riveted or lap-welded steel plates. Opinions differ as to the merits of these two types. The lap-welded pipe of diameters larger than 30 inches (118 mm.) has been imported from Germany in the past but can now be obtained in America. It is made of soft steel of a tensile strength of 48,000 to 56,000 pounds per square inch (3370 to 3940 kg. per square cm.). Transverse joints are riveted, except under high



Typical Riveted Pipe. Pipe Line No. 3, Pacific Gas & Electric Corporation, at Electra, Calif. Triple-riveted butt-strap pipe with anchorage. Diam. of pipe 42″ (106.7 mm).

heads, in which case they are flanged and bolted. The riveted pipe is usually made from medium steel plates of a tensile strength of 60,000 to 65,000 pounds per square inch (4210 to 4570 kg. per sq. cm.). In thin plates for pipe under pressures,

lap joints double riveted, of 70 per cent. efficiency, are used; while for higher heads, butt joints with inside and outside plates and triple lines of rivets, of 80 per cent. efficiency, are used. Transverse joints are double riveted under high heads, and single riveted under low heads.

The following list of installations will give some idea of present practice.

Pacific Gas & Electric Co. Electra Pipe No. 3 (1905).—Maximum head 1260 feet (384 m.). Riveted pipe throughout. Diameter 36 inches (915 mm.) at the lower end; $\frac{13}{16}$ inch (20.6 mm.) thick.

Drum Plant (1913).—Maximum head 1375 feet (433 m.). Length 6282 feet (1930 m.). Riveted pipe throughout. Diameter 72 inches (1830 mm.) at the top and 52 inches (1320 mm.) at bottom, where the plates are 1¼ inches (31.8 mm.) thick.

Sierra & San Francisco Power Co. Stanislaus.—Maximum head 1495 feet (470 m.). Upper portion 1200 feet (377 m.) of 66-inch (1670 mm.) wood stave pipe. Lower portion 3000 feet (943 m.) of riveted pipe. The upper part of riveted pipe is 48⅞ inches (1244 mm.) in diameter and ¼ inch (6.35 mm.) thick. It decreases to 40 inches (1015 mm.) diameter at the bottom; 1 inch (25.4 mm.) thick.

Boulder, Colorado. Head 1830 feet (558 m.). Length 9800 feet (2990 m.). Riveted pipe throughout. Diameter varies from 56½ inches (1435 mm.) at top to 44 inches (1117 mm.) at bottom, with a plate thickness of 1¾ inches (44.5 mm.).

Among other plants having riveted pipes, may be mentioned those at Cascade Creek, Colo.; City of Tacoma at Nisqually; City of Seattle at Cedar River; Great Northern Power Co. at Duluth; Portland Railway Light & Power Co. at Bull Run; Pacific Gas & Electric Co. at Centerville and Deer Creek; and the Southern Sierras Power Co. on Bishop Creek.

The use of the lap-welded pipe is general, usually in combination with riveted pipe, the former being used for the higher heads. A few examples will illustrate its use.

Necaxa, Mexico. The upper portion of the pipes consists of a section 8 feet (2.44 m.) in diameter, followed by 2200 feet (670 m.) of 6-foot (1.83 m.) riveted pipe. The lower portion consists of six pipes, 30-inch (762 mm.) diameter welded pipe,

2460 feet (750 m.) long, under a maximum head of 1452 feet (443 m.).

Great Western Power Co. Las Plumas.—Four lap-welded pipes, 5 feet (1.52 m.) diameter, and one lap-welded pipe 6 feet (1.83 m.) diameter, under a final head of 450 feet (137 m.). Transverse joints are riveted. The pipes are about 600 feet (183 m.) long, and connect to a riveted steel header and discharge pipe.

San Joaquin Light & Power Co. San Joaquin No. 1.—Lap-welded pipe 44 inches to 34 inches (1117 to 863 mm.) diameter,

Typical Lap-Welded Pipe. Great Western Power Co., Las Plumas, Calif. Installing 6 ft. diam. (1885 mm.) lap-welded pipe No. 5.

4293 feet (1307 m.) long, under a maximum head of 1411 feet (430 m.).

Adamello, Italy. Riveted pipe down to a head of 722 feet (220 m.). Below that, lap-welded pipe to a total head of 2980 feet (910 m.). The welded pipe has riveted joints down to 1870 feet (570 m.) head and below that, flanged and bolted joints.

Pacific Light & Power Corporation. Big Creek No. 1.—Welded pipe 4500 feet (1370 m.) long, under maximum head of 2146 feet (656 m.). Diameter at top 42 inches (1066 mm.),

at bottom 24 inches (610 mm.). Riveted transverse joints used down to head of 1460 feet (445 m.), and thence flanged and bolted joints.

Georgia Railway & Power Co. Tallulah Falls.—Five penstocks, each 5 feet (1.52 m.) diameter, 1250 feet (381 m.) long, under a maximum head of 612 feet (187 m.). About one-half of each pipe, down to a head of 483 feet (147 m.) was of riveted plates, and the balance of welded pipe with riveted transverse joints.

Typical Low Head Plant. Construction Detail of Power House. Georgia-Carolina Power Co., Stevens Creek Plant.

The best construction requires that the penstocks should be placed upon concrete supports from fifteen to twenty feet apart, and anchored at intervals by a steel strap passing over the pipe and fastened to the concrete or bed rock. Pipes are covered with earth, especially in cold regions. At the upper end, an expansion joint is used when making connection with the conduit.

At one time it was deemed possible to form the penstocks of a pressure tunnel in the rock of a mountain side, lining the tunnel with concrete and depending upon the resistance of the

rock to prevent bursting. Several bad failures of this type of construction, notably that at Kern River Plant No. 1 and in a pressure tunnel on the Los Angeles Aqueduct, would seem to indicate that this method of building a penstock is not a good one.

Valves and Accessories.

In the beginning it was customary to provide a header or manifold back of the power house, into which all of the penstocks entered and from which all of the water wheels took water without reference to the various turns the water would take. This practice has been abandoned in favor of leading one pipe directly to a wheel, or if to two wheels, to separate the water by a "Y" with branches leading directly to each wheel.

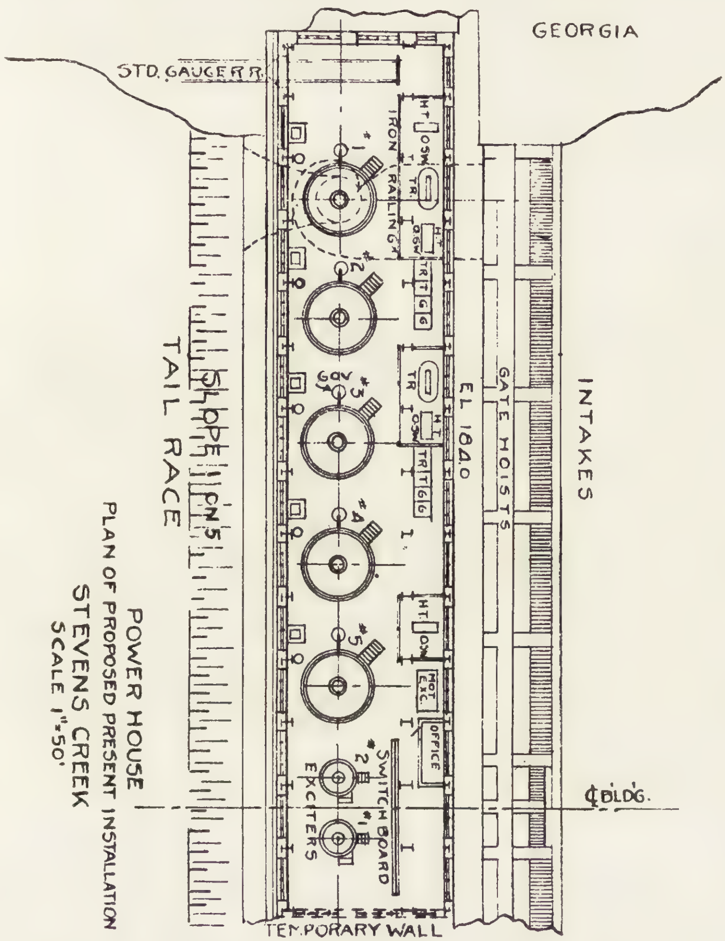
It is customary to place gate valves at the junction of the conduit and the penstock, operated either by hydraulic or electric motor and controlled from the power house. In some cases, butterfly or pivot valves are used, and in New York a Johnson valve was used at the Salmon River plant. At the power station in high head plants, hydraulic or electric-motor operated gate valves are used back of the water wheel. In medium head plants, where the pipe diameter is large, butterfly or pivot valves are used, operated by hydraulic cylinders.

On the pipe lines, manholes are provided and in some instances air valves are installed, although, unfortunately, engineers as a rule are not yet convinced of the necessity for such valves. On the fifth pipe line of the Great Western Power Company, two 8-inch (203 mm.) air valves were placed on the line of pipe, and at the junction with the tunnel header, four such valves were installed.

LOW HEAD PLANTS.

The development of hydraulic power by turbines had reached a definite form at the time when the transmission of electric power began, and, hence, in low head plants a well defined practice was available as a precedent. Such plants, as a rule, are situated on the stream at or near some definite fall, where a diverting dam will turn the water immediately into the power station. Good examples of such plants are the plants of the Washington Water Power Company at Post Falls, Little

Falls and Long Lake, on the Spokane River, the latter a 50,000-kw. plant; the Mississippi Power Company at Keokuk, of an ultimate capacity of 225,000 kw.; the McCalls Ferry, Pa., plant

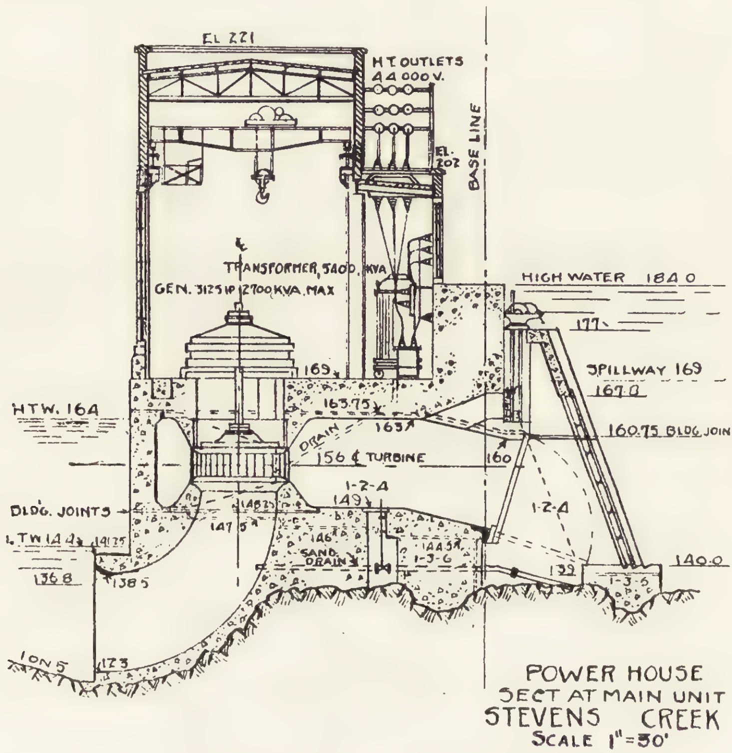


Typical Low Head Plant. Floor Plan. Georgia-Carolina Power Co., Stevens Creek Plant.

of 92,500 kw. capacity; and the Alabama Power Company at Coosa Lock No. 12, of an ultimate capacity of 78,000 kw.

In some cases the water is carried into a canal or headrace by a diverting dam. Examples of this type are the Cedars

Rapids, Province of Quebec, plant of 120,000 kw. ultimate capacity; the three plants of the Niagara Falls Power Company; the plant of the Electrical Development Company; and the plant at Trollhättan, Sweden; some of the largest built. Other low head plants lead water to the plant through large steel pipes, over a considerable distance. Examples of this type are



Typical Low Head Plant. Section, Georgia-Carolina Power Co., Stevens Creek Plant.

the 165,000 kw. plant of the Ontario Power Company at Niagara Falls, where the pipes are 6500 feet (1980 m.) long; the 21,000 kw. plant at Great Falls, Mont., where the pipe is 2350 feet (717 m.) long; and the Condit plant on White Salmon River, Wash., where the pipes are very large. This feature often limits the size of the generating units. Table No. 5 of the

Appendix is a partial list of low head plants, all operated by hydraulic turbines.

THE STATION DESIGN.

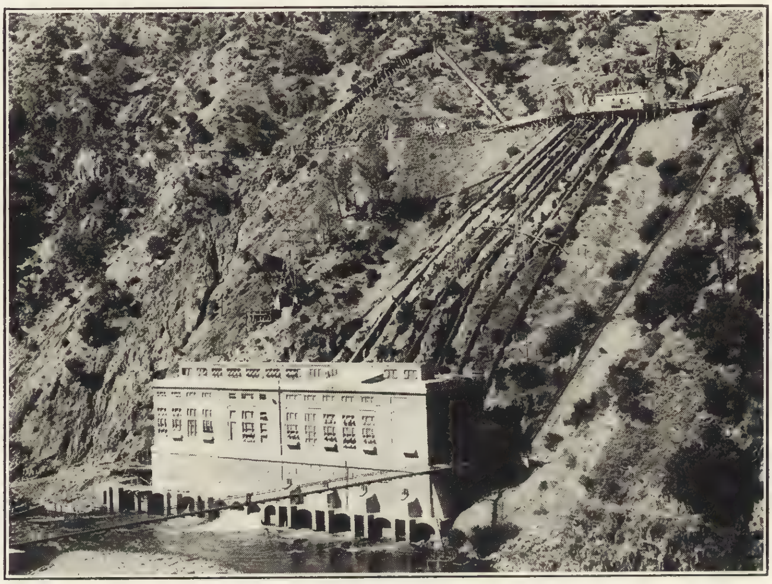
While the voltage of transmission lines shows a tendency to increase, with a resulting modification in the arrangement and size of power station buildings, the general plan can be considered as fairly well settled, so far as the hydraulic end is concerned. The evolution of electric machinery, involving changes in the size and arrangement of electrical parts, such as switches or transformers, has produced types of apparatus the design of which is fixed within reasonable limits. An instance of the changes of recent years is the use of a double system of bus bars instead of one, thus insuring greater safety and a more flexible station. This has been caused, largely, by the larger size of the stations and the units installed therein. This paper does not include a consideration of the electrical part of the development, but reference is made to this phase of the subject to show present tendencies.

Unless special conditions determine otherwise, the design of modern, medium and high head plants follows a general plan. The pipes descend the hillside and pass under the main floor of the building to the power units, which are placed on the river side. The transformers are placed in compartments directly behind the generator space. The low tension switches and switchboard are placed above the main floor, the switchboard being in a gallery overlooking the station. The length of the station is generally controlled by the size of the transformers, rather than by the power units.

In low head plants, the station building is often built in as a part of the diverting dam, and the penstocks become passages in the masonry of the dam. More often, short penstocks of large steel pipes lead from the dam or forebay directly to the wheels. In special cases, such as at Niagara Falls, the position of the turbines in a wheel pit makes necessary an unusual arrangement. This form of plant, necessary in the particular case, should not form a precedent, as it probably did in the case of the first plant at Snoqualmie Falls, where the plant in a chamber in the rock was wholly unnecessary.

The Power Unit.

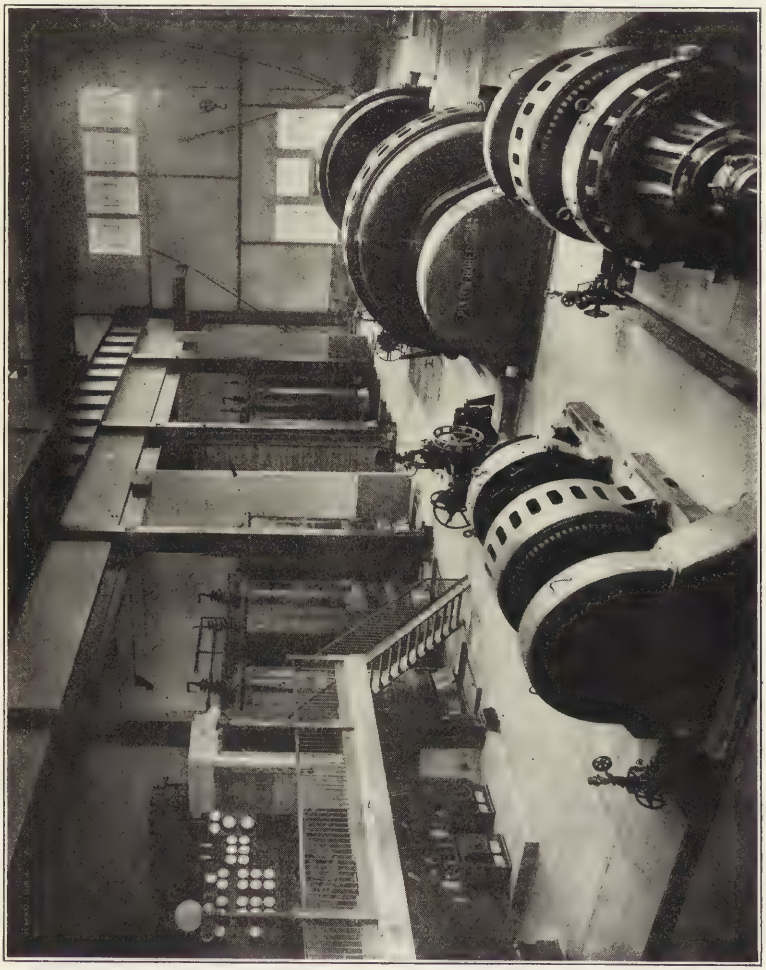
The range of head determines at the two extremes the type of water motor. For units under low head and of even moderate size, 1000 kw. or over, the turbine is practically the only available wheel. For high heads, above 1000 feet (305 m.), the impulse wheel is the only motor which can be used. Between these two extremes both types of wheels are available. As the size of units grows larger, the tendency is to use turbines on higher and higher heads. Examples of high head turbines are



Typical Medium Head Plant. Great Western Power Co., Las Plumas, Calif.

shown in Table No. 3, where the 9700 hp. turbine at Centerville, under 565 feet (172 m.) head; the 18,000 hp. turbines at Las Plumas, under 465 feet (142 m.) head; the 16,000 hp. turbines, under 580 feet (176.7 m.) head, at Tallulah Falls; and the 6000 hp. turbines, under 670 feet (202.1 m.) head, at Noriega, Mexico, are representative. Some turbines under 750 feet head are contemplated and there seems to be no reason why turbines under heads of 1000 feet should not be used. On account of the high velocity of water, the rotational speed is

high and passes the limits of standard generator construction, the present limit of which is 514 r. p. m., or at the most, 600 r. p. m. This requires that the specific speed of the wheels be



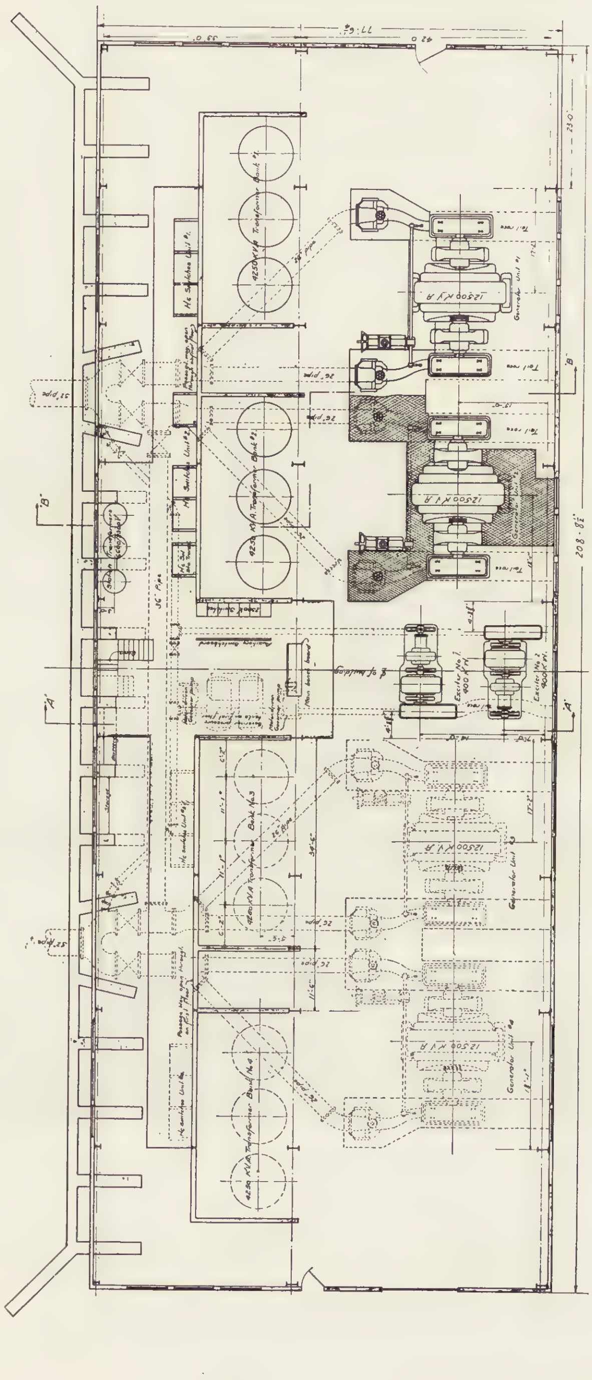
Typical High Head Plant. Pacific Gas & Electric Corporation, Drum Plant, South Yuba River, Calif.

kept as low as possible, in order that the rotation speed be reduced. The specific speed of the Michoacan, Mexico, unit is 11.68 (52.0 metric); of the Tallulah Falls units, 22.8 (101.6 metric).

On the other hand, extremely low heads demand a slow rotational speed of turbines, with resulting large size of wheel and generator and high specific speed. The Keokuk 10,000 hp. units, under 32 feet (9.75 m.) head, have a specific speed of 75.8 (337.4 metric), a speed of 57.7 r. p. m., and a diameter of 15 ft. 7 in. (4.75 m.). The Cedars Rapids, Canada, units, under 30 feet (9.15 m.) head, have a specific speed of 83.3 (366.2 metric) and a speed of 55.6 r. p. m. These represent the present development of low head high power units.

The design of American turbines is rapidly reaching such a high efficiency that little further progress can be expected. By systematic tests of model runners, at Holyoke, and study of the design, turbines have been built which, tested in position, give efficiencies of over 93 per cent. It has been found that in large size units a higher efficiency can be obtained from the wheel as built than from the model runner tested at Holyoke. It may be remarked, that in wheels of high specific speed the curve of efficiency is high at one point of power output and drops off more rapidly either way than for low specific speeds, thus making the efficiency considerably less at part loads. This is not very important, for in plants of even ordinary capacity there are usually a number of units operating, allowing most of them to be operated at outputs corresponding closely to maximum efficiency, while the load changes are taken by one unit, or by placing one unit in or out of service at a time.

The facts, that efficiencies of turbines range from five to seven per cent higher than impulse wheels; that in most cases one to three per cent of the head can be saved by the draft tube; and that for large size units the turbine is more adapted to economical speeds, indicate the reasons why there is a tendency to use turbines in preference to impulse wheels for heads up to 1000 feet. On the other hand, the impulse wheel is being adapted to very high heads, as in Switzerland, and under the head (effective) of 1900 feet (570 m.), the Big Creek, California, plant wheels are operating the present largest hydroelectric unit, 17,500 kv-a. It may be noted here that the Girard type of impulse wheel has been tried and found wanting in efficiency and service. In one case, five of these wheels have been replaced by turbines. It can be stated as a result of ex-



Typical High Head Plant. Pacific Gas & Electric Corporation, Drum Plant, South Yuba River. Plan of Power Station.

perience that this type of wheel is no longer considered available in America.

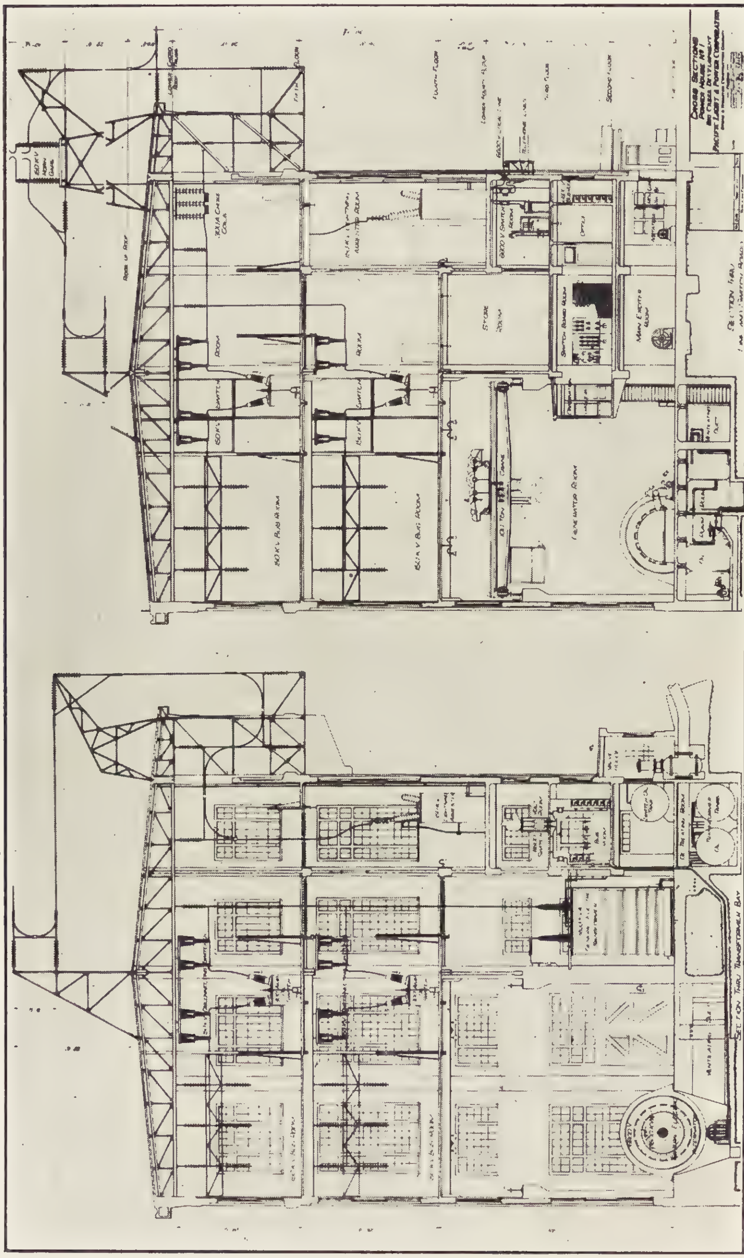
Some attempts have been made in the past to increase the

Typical High Head Plant. Pacific Light & Power Corporation, California, Big Creek Plant No. 1.

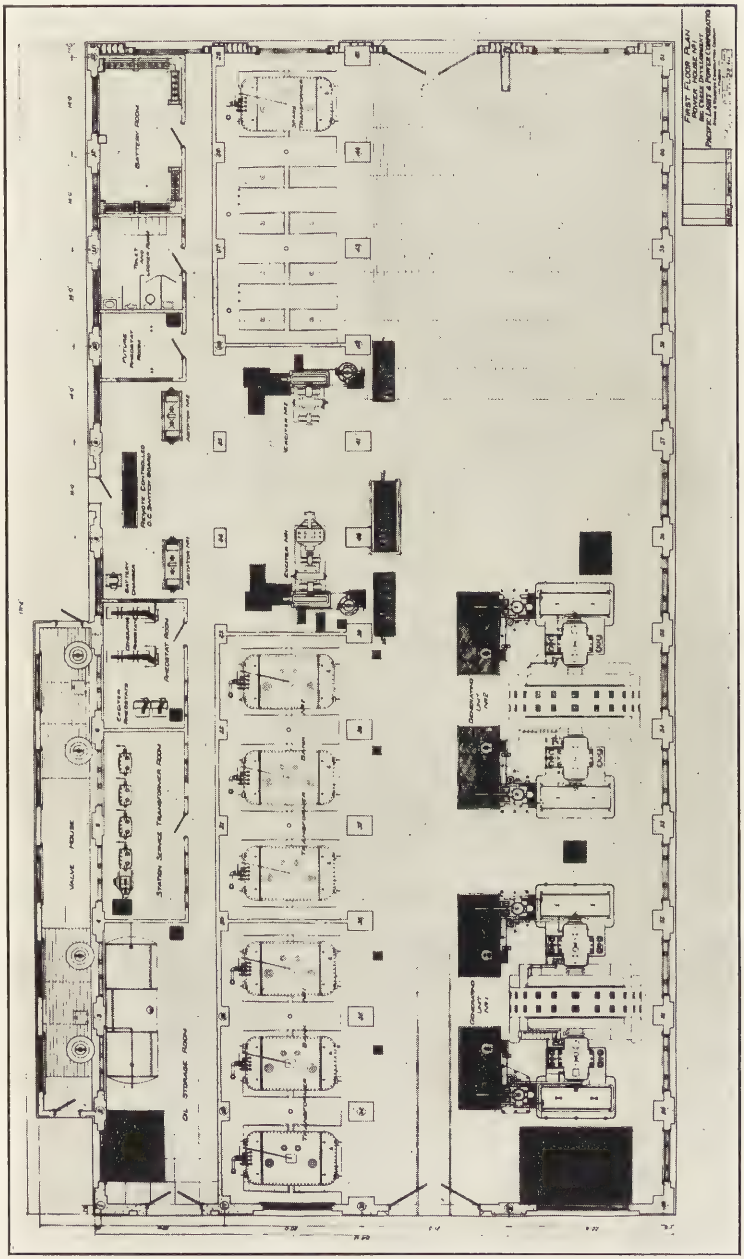
number of nozzles on one impulse wheel, in order to increase the power from one unit. At Necaxa, Mexico, two nozzles, and at Rio Janeiro, four nozzles, were used on one wheel. These units are on vertical shafts. There seems to be no doubt but

that more than one nozzle discharging in the same wheel case, whether on one wheel or upon different wheels, reduces the efficiency of the unit and also renders the governing mechanism difficult to design and operate. The present tendency seems to be to adhere to the impulse wheel on a horizontal shaft, with one nozzle. If the capacity of the unit is beyond that of one wheel, two are used, one on each end of the generator, with connected governing apparatus. If the capacity of the unit is too large for two wheels with one nozzle each and with the most economical speeds of the generator, then lower speeds would be used, even at increased cost of generator; and if this is not possible, then the number and size of units should be changed, or a turbine used. The use of vertical shaft units and multiple nozzles on impulse wheels is more favored by European than by American engineers.

In the building of turbine driven units, both vertical and horizontal shafts are standard practice at the present time. In the case of horizontal units, the discharge from twin runners into a common draft tube has been found to result in greater hydraulic losses than when the draft tubes are separated, and some units have been constructed with a separate wheel and draft tube at each end of the shaft. The vertical shaft unit is a later development, and is necessary in special cases, such as at Niagara Falls or at Las Plumas, where the height of floods made it necessary to place the generator above the turbine. At first, a simple bearing of two steel discs, lubricated by oil under pressure, were used, but latterly two special types of bearing have been used with success. The Kingsbury is a babbitted bearing and runs in oil under gravity pressure. The roller bearing of the Standard Roller Bearing Company provides a cage in which are placed a number of hard steel cylindrical rollers placed between the discs of an ordinary bearing. The bearing runs under oil pressure and normally the oil pressure relieves the rollers of the weight; but in case of failure of the oil supply, the rollers take the load. Both of these types of bearing are in operation. At Cedars Rapids, the Kingsbury bearings carry a load of 550,000 pounds (250,000 kg.) at 55.6 r. p. m., while at Las Plumas, a roller bearing carries 240,000 pounds (109,000 kg.) at 400 r. p. m.



Typical High Head Plant. Section of Power House. Pacific Light & Power Corporation, Big Creek Plant No. 1. Head 2146 ft. (656 m.)



Typical High Head Plant. Pacific Light & Power Corporation, California, Big Creek Plant No. 1. Plan of Power House.

There was a tendency at one time to install turbines acting under high heads, and with long penstocks, without relief valves, but this was soon seen to be impossible in operation. The relief valves at first installed were operated by pressure only, but present practice is to make the relief valves of large capacity and under direct control of the governors, either by oil under pressure or by direct mechanical connections.

In the setting of turbine units, the general practice is to take the water from the forebay in steel penstocks, guide it to the runner through a spirally shaped case of cast iron or cast steel, and discharge it through a steel plate or cast iron draft tube. Some variation from this practice has recently been made in some low head plants, as at the Central Georgia Power Company plant on the Ocmulgee River, the plant of the East Tennessee Power Company on the Ocoee River, and at Keokuk, where the water passages, including penstock and draft tubes, are all formed in concrete.

In the case of auxiliaries in the plants, in the past the practice has been to provide each power unit with independent machines, except the exciters. However, in some recent plants a central system of oil pumps, supplying oil for all the governors in the station, has been installed; and in case of oil being needed under pressure for step-bearings of vertical units, it is also supplied from a central system of pumps, separate from that of the governor oil. Exciters are installed in duplicate and provided with water motors, one unit having an electric motor drive in addition.

The size of hydro-electric units has been referred to above. There does not seem to be any halt in the design of larger and larger units. Up to 1904, the 3750 kw. units at Niagara Falls were the largest, while numbers of 2000 kw. units, water-wheel driven, were installed in the West. The 7500 kw. unit of the Canadian Niagara Falls plant was placed in operation in 1905. The 5000 kw. unit at de Sabla, Cal., 1904, remained a standard in the West for several years, until in 1908 the 10,000 kw. units at Las Plumas, Cal., were put in operation. A number of units of 12,000 to 13,500 kw. which are now in operation, and the 17,500 kv-a. units at Big Creek, Cal., represent present maxima. There seems to be no reason why the increase in size should be

limited to these amounts in stations where a large amount of power is developed. A unit of 25,000 kw., with a single runner turbine of 36,000 hp., was projected in 1913, and manufacturers were ready to build it. A steam unit turbine of 35,000 kw. capacity was built in 1914, and such practice indicates the possibilities of hydro-electric design.

The size of power plants has increased correspondingly, and from plants of 200 and 300 kw. capacity twenty-three years ago, the development has increased so that plants of 50,000 kw. capacity are common, while plants such as at Keokuk and Cedars Rapids represent the largest American development, exceeded in capacity only by a few plants in Norway.

The development of hydro-electric power has proceeded at a rapid rate, with a corresponding conservation of the coal of the world. In the United States the only obstacle in the path of still greater development is the well defined policy, both state and national, to hamper all private initiative by restrictive legislation. This tendency is directed particularly against hydro-electric development and, unless changed, will ultimately bring to a standstill a progress that in the past has been most beneficial to the nation, and which has been the only true conservation of the existing fuel supply.

In this paper, the data given in tables are obtained largely from engineering journals and may be subject to error, especially as the first part of a development is that generally recorded, and accounts of later extensions and changes of plans may never appear in print. In particular, European practice is only reported in a fragmentary way in American journals, and the writer did not have the time to review European publications. It is to be hoped that some one more familiar with such practice will add some data as a discussion. It is also apparent that some statements as to present practice have been made with which others may not agree, and this variation may well be set forth in the discussion.

Owing to the nature of the paper, it has been necessary to repeat information and to reprint diagrams and photographs which have already appeared elsewhere. The writer desires to acknowledge the courtesy of those who have furnished data, notably Mr. C. F. Uhden, Chief Engineer of the Washington

Water Power Company, Mr. F. G. Baum, Consulting Engineer of the Pacific Gas & Electric Corporation, Mr. Albert S. Crane, Hydraulic Engineer of the J. G. White Engineering Corporation, The Stone & Webster Engineering Corporation, Mr. P. W. Ham, of the Great Western Power Company, Mr. W. A. Doble, of the Pelton Water Wheel Company, and the Pacific Tank & Pipe Co.

APPENDIX.

TABLE NO. 1. DATA ON EARLY ALTERNATING CURRENT PLANTS.

Plant From	Plant To	Date of Operation	Dist. Miles	Power	Voltage Gen.	Voltage Line	Remarks
Oregon City	Portland, Ore.	1889	13.0	720 kw.	4,000	4,000	Single-phase
Plant	Bodie, Cal.	1893	13.0	150 hp.	3,500	3,500	" "
San Antonio	Pomona, Cal.	1891	15.0	150 hp.	1,000	10,000	" "
Plant	Walla Walla, Wash.	1893	4.0	100 hp.	2,000	2,000	" "
Plant	Telluride, Colo.	1890	5.0	400 hp.		3,000	" "
Tivoli	Rome, Italy	1892	18.0	1,000 hp.		5,000	Ganz system
Gorzente	Genoa, "		18.0	1,000 hp.		8,000	" "
Paderone	Fiume, "		3.5	100 hp.		3,000	" "
Lauffen	Frankfort, Germany	1891	105.0	300 hp.	50	12,000	Three-phase
Mill Creek	Redlands, Cal.	Sept. 1893	7.5	250 kw.	2,500	11,000	" "
Lauffen	Heilbronn, Germany	1893	7.0	200 hp.	50	5,000	" "
Plant	Gringesberg, Sweden	1893	8.0	400 hp.	400	5,000	" "
Plant	Guadalajara, Mexico	1893	18.0	350	1,040	11,000	" "
Baltic	Taftville, Conn.	1894	4.5	400	2,500	2,500	" "
Sewells Falls	Concord, N. H.	1894	4.0	400	2,200	2,200	" "
Folsom	Sacramento, Cal.	July 1895	21.5	3,000 kw.	800	11,000	" "
Niagara Falls No. 1		Oct. 1895		3,730 kw.	2,200	11,000	Two-phase
Oregon City	Portland, Ore.	1895	14.3	1,350 kw.	6,000	6,000	Three-phase
Yuba River	Nevada City, Cal.	Feb. 1896	8.0	1,400 kw.	5,500	5,500	Two-phase
San Joaquin River	Fresno, Cal.	May 1896	35.0	1,020 kw.	700	11,000	Three-phase
Niagara Falls	Buffalo, N. Y.	Nov. 1896	26.0		2,200	11,000	Two-phase
Kern River	Bakersfield, Cal.	Mar. 1897	14.5	900 kw.	550	11,500	Three-phase
Provo	Murcur, Utah	Feb. 1898	32.0	1,500		40,000	" "
Mill Creek	Los Angeles, Cal.	1899	86.0			33,000	" "
Colgate	Oakland, Cal.	June 1901	141.0			40,000	" "

TABLE NO. 2. DATA ON HIGH HEAD PLANTS.

Over 750 feet (228 m.) head. All impulse wheels, unless noted.

No.	Power Co., Location, State and Year	(a) Present Installed kw. (b) Total Future Available kw.	Size and Number of Generators	Size and Number of Imp. Wheels to one Generator	Head T.=Total E.=Effective Feet	Meters	Remarks
1	Pac. Gas & El. Co., de Sabla, Cal., 1903-04	(a) 14,000 (b) 14,000	2-5,000 kw. 2-2,000 kw.	1 Wh., 1 Noz. to each generator	T. 1,530 E. 1,440	466 439	6,340 ft. Penstock
2	Pac. Gas & El. Co., Electra, Cal., 1899-1904	(a) 20,000 (b) 20,000	2-5,000 kw. 5-2,000 kw.	1 Wh. 7,500 hp. 2 Wh. 3,700 hp.	T. 1,467 E. 1,395	447 426	6,597 ft. Penstock
3	Pac. Gas & El. Co., Drum, Cal., 1913	(a) 25,000 (b) 50,000	2-12,500 kv-a.	2-8,500 hp. Sing. Noz.	T. 1,375 E. 1,345	419 407	6,272 ft. Penstock
4	Pac. Gas & El. Co., Deer Creek, Cal., 1908	(a) 5,500	1-5,500 kw.	7,400 hp., 2 Sing. Noz. Wheels	E. 837	255	
5	Sierra & S. F. P. Co., Stanislaus, Cal., 1907-1908	(a) 34,000 (b) 75,000	4-8,500 kw.	2-6,000 hp. Sing. Noz.	T. 1,495 E. 1,460	456 446	4,505 ft. Penstock
6	S. Joaquin Lt. & P. Co., San Joaquin No. 1, 1911	(a) 19,000 (b) 19,000	4-4,000 kv-a. 1-3,000 "	1-Two-Noz. Wheel	T. 1,420	433	4,070 ft. Penstock
7	Pac. Lt. & P. Co., Big Creek No. 1, Cal., 1913	(a) 35,000* (b) 70,000*	2-17,500 kv-a.	2-10,000 hp. 1-Fixed Noz.	T. 2,146 E. 1,900	656 570	9,960 ft. Conduit 4,500 ft. Penstock
8	Pac. Lt. & P. Co., Big Creek No. 2, Cal., 1913	(a) 35,000* (b) 70,000*	2-17,500 kv-a.	2-10,000 hp. 1-Fixed Noz.	T. 2,026 E. 1,780	618 543	21,300 ft. Conduit 4,500 ft. Penstock

* kv-a.

9	L. A. Aqueduct	(a) 22,500	3-7,500 kw.	2-7,000 hp.	T.	941	288	Tunnel, surge tank
	San Francisquito No. 1, 1913	(b) 45,000		Sing. Noz.	E.	905	278	and penstock
10	L. A. Edison Co.,	(a) 20,000	4-5,000 kw.	2-10,750 hp.	E.	865	264	Penstock
	Kern River No. 1, Cal., 1907			Sing. Noz.				
11	So. Sierras P. Co.,	(a) 6,000	3-2,000 kw.	Sing. Imp. Wheels	T.	938	286	10,025 ft. Conduit
	Bishop Creek No. 2, Cal., 1913	(b) 6,000		1-Nozzle	E.	845	258	
12	So. Sierras P. Co.,	(a) 6,750	3-2,250 kw.	Sing. Imp. Wheels,	T.	814	248	13,500 ft. Conduit
	Bishop Creek No. 3, Cal., 1908	(b) 6,750		1-Nozzle	E.	730	223	4,630 ft. Penstock
13	So. Sierras P. Co.,	(a) 6,000	3-1,500 kw.	Sing. Imp. Wheels,	T.	1,120	342	8,700 ft. Conduit
	Bishop Creek No. 4, Cal., 1905	(b) 6,000	2-750 kw.	1-Nozzle	E.	1,050	320	3,000 ft. Penstock
14	Mt. Whitney P. Co.,	(a) 2,000	2-1,000 kw.	1 Runner, 1 Nozzle	T.	1,135	346	2,844 ft. Penstock
	Tule R. No. 1, Cal., 1909	(b) 4,000						
15	No. Cal. Power Co.,	(a) 6,650	1-2,000 kw.	1 Sing. Noz. Wheel	T.	1,196	265	1-6,200 ft. Penstock
	Volta, Cal., 1901-6-8		1-2,400 kw.	to each	T.	1,250	281	1-8,400 ft. Penstock
			3-750 kw.					
16	No. Cal. Power Co.,	(a) 6,000	2-1,500 kw.	2-R., 1-Noz.	T.	1,200	366	6,000 ft. Penstock
	Kilarc, Cal., 1908-11		1-3,000 kw.	1-R., 1-Noz.				
17	Puget Sd. Tr., Lt. & P. Co.,	(a) 14,000	4-3,500 kw.	2-Wheels with Sing.	T.	872	266	Penstock
	Electron, Wash., 1904	(b) 22,000		Nozzle				
18	Telluride P. Co.,	(a) 2,400	1-2,400 kw.	2-Imp. Whls. at	T.	1,768	539	5,200 ft. Penstock
	Battle Cr., Utah, 1908	(b) 2,400		one end of shaft				
19	Animas Canal, R. W. P. Invest. Co.,		2,250 kw.	1-4,000 hp. Sing.	E.	970	296	
	Cascade Cr., Colo., 1905			Runner 1-Nozzle				
20	Cen. Colo. P. Co.,	(a) 10,000	2-5,000 kw.	1-10,500 hp.	T.	1,830	558	9,800 ft. Penstock
	Boulder, Colo., 1910			1-Nozzle	E.	1,797	507	

TABLE NO. 2. DATA ON HIGH HEAD PLANTS.—Continued.

Over 750 feet (228 m.) head. All impulse wheels, unless noted.

No.	Power Co., Location, State and Year	(a) Present Installed kw. (b) Total Future Available kw.	Size and Number of Generators	Size and Number of Imp. Wheels to one Generator	Head T.=Total E.=Effective Feet	Meters	Remarks
21	Arizona P. Co., Verde R., 1910	(a) 5,400	3-1,800 kw.	1-3,000 hp. Imp. Wheel	T. 1,100	335	33,100 ft. Conduit 4,800 ft. Penstock
22	Mex. Lt. & P. Co., Necaxa, 1906-10	(a) 50,000	6-5,000 kw. 2-10,000 kw.	1-9,000 hp., 2-Nozzle	T. 1,452 E. 1,300	443 397	
23	Rio Janeiro T. L. & P. Co., Pirahy, P. S., Brazil, 1913	(a) 94,000 hp.	6-9,000 hp. 2-20,000 hp.	S. Wh. 4-Noz. 20,000 hp.	E. 900	275	
24	Cia Docas de Santos, Brazil, 1910	(a) 15,000 (b) 75,000	5-3,000 kw.	Impulse Wheels	T. 2,100	640	
25	Hyd. El. P. Sup. Co., Tata, India, 1913	(a) 32,000 (b) 64,000	8,000 kw.	1-11,000 hp. Wh. 1-Noz.	T. 1,727 E. 1,661	526 548	13,000 ft. Penstock
26	British Al. Co., Loch Leven, Scot.,	(a) 19,000	9-Twin Gen. of 1,000 kw.	1 Imp. Whl. to 2 Gen.	E. 890	272	18,000 ft. Conduit
27	Campo-Cologno, Brusio, Switz., 1906	(a) 35,000 hp. (b) 40,000 "	10-3,500 hp.	Girarde & Impulse	T. 1,440	440	5 Penstocks
28	Adamello, Isola, Italy, 1910	(a) 26,000 (b) 45,500	4-6,500 hp.	6,500 hp. Whl. 1-Df. Noz.	T. 2,968 E. 2,800	910 854	4,900 ft. Conduit
29	Arniberg, Switz., 1912			3,000 hp. Imp. Wh. 1-Noz.	E. 2,800	854	

TABLE NO. 3. DATA ON MEDIUM HEAD PLANTS.

200 feet (61 m.) to 750 feet (228 m.) head.

No.	Power Co., Location, State and Year	(a) Present Installed kw. (b) Total Future Available kw.	Size and Number of Generators	Size, Type and Number of Wheels to one Generator	Head T.=Total E.=Effective Feet	Meters	Remarks
1	Pac. Gas & El. Co., Colgate, Cal., 1889-1901	(a) 14,200 (b) 14,200	3-900 kw. 3-2,000 kw. 1-3,500 kw.	1 Wh., 1 Noz. 2 Wh., 1 Noz.	T. 698 E. 668	213.0 203.5	8-mi. Conduit
2	Pac. Gas & El. Co., Centerville, Cal., 1900	(a) 6,400 (b) 6,400	1-5,500 kw. 1-900 kw.	1-9,700 hp. Single Run. turbine	T. 577 E. 565	176.0 172.0	8-mi. Conduit
3	Grt. West. P. Co., Las Plumas, Cal., 1908-14	(a) 50,000 (b) 80,000	5-10,000 kw.	5-18,000 hp. Vert. shaft Sing. Run.	E. 465	141.7	15,168 ft. Pressure tunnel
4	Pac. Lt. & P. Co., Borel Plant, Kern R., Cal., 1904	(a) 10,000 (b) 10,000	5-2,000 kw.	5-4,000 hp. Sing. Run. turbines	T. 260	97.5	Forebay and Penstocks
5	No. Cal. P. Co., Coleman, Cal., 1911	(a) 12,000	3-4,000 kw.	1-7,000 hp. Sing. Run turbine	T. 487	148.2	3,600 ft. Penstock
6	No. Cal. P. Co., South P. P., Cal.	(a) 4,000	1-4,000 kw.	2-3,300 hp. Imp. Whl.	T. 515	157.0	1,980 ft. Penstock
7	No. Cal. P. Co., Inskip, Cal.	(a) 6,000	1-4,000 kw. 1-2,000 kw.	3-Run., 1-Noz. 3-Run., 1-Noz.	T. 370	112.7	3,162 ft. Penstock
8	Portland Ry. Lt. & P. Co., Bull Run, Ore.	(a) 11,250	3-3,750 kw.	3-6,400 hp. horizontal shaft	T. 320	97.5	33,030 ft. Conduit and Forebay

TABLE NO. 3. DATA ON MEDIUM HEAD PLANTS.—Continued.

200 feet (61 m.) to 750 feet (228 m.) head.

No.	Power Co., Location, State and Year	(a) Present Installed kw. (b) Total Future Available kw.	Size and Number of Generators	Size, Type and Number of Wheels to one Generator	Head T.=Total E.=Effective Feet	Meters	Remarks
9	Tacoma Mun. Plnt., Nisqually, Wash., Nov. 15, 1913	(a) 20,000	4-5,000 kw.	Single Run. 8,000 hp. turbine	T. 425	129.5	11,355 ft. Conduit and Forebay
10	Seattle Mun. Plnt., Cedar R., Wash., 1912	(a) 10,500	2-4,000 kw. 2-1,250 kw.	Sing. Runner Turb. Imp.	T. 614 E. 584	187.0 178.0	16,816 ft. Penstock
11	Puget Sd. Tr., Lt. & P. Co., White Riv., Wash., 1912	(a) 20,000 (b) 40,000	2-10,000 kw.	1-18,000 hp. Sing. Run.	T. 480 E. 440	146.2 138.2	2,850 ft. Penstock
12	Puget Sd. Tr., Lt. & P. Co., Snoqualmie No. 1, Wash., 1898	(a) 11,000 (b) 11,000	4-1,500 kw. 1-5,000 kw.	6-Run, 2-Noz. 1-Sing. Run.	E. 270	82.3	Dam and short Penstock
13	Puget Sound Tr., Lt. & P. Co., Snoqualmie No. 2, Wash.	(a) 8,750 (b) 26,350	1-8,750 kv-a.	1-10,000 hp. Sing. Run. turbine	E. 270	82.3	1,035 ft. Conduit 466 ft. Penstock
14	Utah P. & L. Co., Grace, Ida., 1909 1913	(a) 11,000	2-5,500 kw.	Twin-Runner turbines 2-16,500 hp. turbines	T. 510 E. 450 E. 482	155.5 137.0	26,428 ft. Penstock
15	Grt. No. P. Co., near Duluth, Minn., 1907	(a) 30,000 (b) 60,000	4-7,500 kw.	13,000 hp. Sing. Run. turbine	T. 378 E. 355	115.1	1 mile of Penstock
16	Cleveland Cliffs Iron Co., Carp R., Mich., 1912	(a) 5,600 kv-a.	2-2,800 kv-a.	4,000 hp. Sing. Run turbine	T. 622 E. 580	189.5 176.7	19,300 ft. Conduit, Penstock

17	Ga. Ry. & P. Co., Tallulah Falls, Ga., 1913	(a) 50,000 (b) 60,000	10,000 kv-a.	16,000 hp. Sing. Run. turbine	T. 612 E. 580	186.2 176.7	6,665 ft. Conduit 1,250 ft. Penstock
18	East. Tenn. P. Co., Ocoee Riv. No. 2	(a) 15,000 (b) 22,500	2-9,375 kv-a.	1-10,000 hp. Dbl. Disch. turbine	T. 250	76.2	
19	Salmon Riv. P. Co., N. Y., 1914	(a) 30,000 (b) 30,000	4-7,500 kw.	1-10,000 hp. Sing. Run.	E. 245	74.7	9,625 ft. Conduit
20	Niag. Falls Hyd. Pr. & Mfg. Co., Plant No. 2	(a) 23,700*		5-2,900 and 4-2,300 hp. turbines	E. 210	39.7	
21	Niag. Falls Hyd. Pr. & Mfg. Co., Plant No. 3	(a) 130,000*		13-10,000 hp. turbines	E. 210	39.7	
22	McBride Sug. Co., Wainiha, Hawaii, 1910	(a) 3,600	3-1,200 kw.	1-2,500 hp., Imp. Wheel, Sing. Noz.	E. 575	175.0	23,000 ft. Conduit 1,700 ft. Penstock
23	Michoacan P. Co., Noriega, Mex., 1911	(a) 10,000	3-3,500 kw.	6,000 hp.	T. 672 E. 670	205.0 202.1	
24	Cataract P. Co., Hamilton, Ont.			3,000 hp.	E. 256	78.0	
25	Tokyo G. & E. Co., Hakon, Japan, 1910	(a) 4,000	2-2,000 kw.	1-2,540 hp. Sing Run., Imp. Wheel	T. 720	219.5	

* kv-a.

TABLE

DATA ON CONDUIT INSTALLATIONS.

No.	Cap. Sec. Ft.	Power Company	Plant	Open Canals	Timber Flumes
1	350	Pac. Gas & El. Co., Cal.	Colgate, 1899		8 mi. 6 ft. x 8 ft. Grade .00254
2	65	Pac. Gas & El. Co., Cal.	de Sabla, 1902-3	8 ft. on top, 3 ft. deep	4 ft. x 6 ft.-short sections
3	120	Pac. Gas & El. Co., Cal.	Electra, 1898	11 ft. wide, 4 ft. deep	4 ft. x 7 ft. Grade .00164
4	350	Pac. Gas & El. Co., Cal.	Drum, 1913	39,600 ft.-7 ft. deep, 11 ft. wide bot.	2,600 ft.
5	2,500	Grt. West. P. Co., Cal.	Las Plumas, 1908		
6	100	S. Joaquin Lt. & P. Co., Cal.	San Joaquin, No. 1, 1911	12,300 ft. of earth canal	715 ft. concr. fl. 966 ft. steel fl.
7	600	Pac. Lt. & P. Co., Cal.	Big Creek, No. 1, 1913		
8	600	Pac. Lt. & P. Co., Cal.	Big Creek, No. 2, 1913		
9	470	Sierra & S. F. P. Co., Cal.	Stanislaus, 1907-8	Open ditch 800 feet	14.8 mi. 6 ft. x 9 ft. Grade .00189
10	320	Truckee Riv. Gen. El. Co.	Fleisch on Truc. R., 1904	2,200 ft. unlined	8,900 ft.-6 ft. x 10 ft. Grade .0005
11	600	Portland Ry. Lt. & P. Co.	Bull Run, 1913	9,250 ft. Con. lined. 13 ft. on bot. Slp. 1:1	18,500 ft.-6 ft. x 9½ ft. Grade .002
12	1,200	Northwest. El. Co., Oregon	White Salmon R., 1913		
13	400	City of Tacoma, Wash.	Nisqually, 1910	1,000 ft. Concr. flume	
14	43	Arizona P. Co.			12,000 ft. concrete 2,200 ft. timber
15	1,500 & 3,000	Puget Sd. Tr. Lt. & P. Co., Wash.	White Riv., 1912	45 ft. wide. Flume inside	
16	1,250	Cen. Colo. P. Co.	Shoshone, 1909		
17	2,000	Grt. No. P. Co., Minn.	St. Louis R., 1907	Earth and Rock R. sec. 30 x 15 ft.	
18	150	Cleveland Cl. P. Co., Mich.	Carp Riv., 1912		
19	230	Mohawk Hyd.-El. Co., N. Y.	Ephratah, 1911		
20	1,650	Ga. Ry. & P. Co.	Tallulah Falls, 1914		
21	1,650	Salmon Riv. P. Co., N. Y.	Salmon R., 1914		
22	1,200	Eastern Tenn. P. Co.	Ocoee Riv., No. 2		4½ miles 9 ft. 9 in. x 14 ft. 2 in.

NO. 4.

MEDIUM AND HIGH HEAD PLANTS.

Wood Stave Pipe	Steel Pipe	Tunnels	Total Length
			8 miles
			12 miles
			About 19 miles
	3,600 ft. riveted		About 8½ miles
		15,168 ft.-220 sq. ft. Max. pressure 87 lbs.	15,168 ft.
		10,755 ft., 5 ft. x 6 ft.	24,736 ft.
	400 ft. of 108 in., 6,480 ft. of 84 in. Grade .0075	3,880 ft. of 12 ft. diameter. Grade .002	10,360 ft.
	250 ft. of 108 in. riveted	21,300 ft. of 12 ft. dia. Grade .0032	21,550 ft.
			15 miles
			10,100 ft.
		5,280 ft. with Fl. 2,640 ft.-10 ft. x 10 ft. lined	33,030 ft.
5,070 ft.-13½ ft. dia. Grade .00094			5,070 ft.
	340 ft.-10 ft. Riv. steel pipe	10,015 ft.-8½ ft. x 10½ ft. Grd. .002	11,355 ft.
4,800 ft. concrete pipe	7,500 ft. steel pipe	10,000 ft.	33,100 ft.
		2,850 ft. of 12 ft. 12 in. concrete lining	
		2½ miles	2½ miles
			About 8,800 feet
10,700 ft.-60 in. Up to 175 ft. head	8,100 ft.-66 in. Lock bar. 500 ft.-66 in. riveted		19,300 ft.
2 miles			2 miles
Max. head 160 ft.		6,665 ft.-151 sq. ft. Grade .002	6,665 ft.
3,450 ft.-12 ft. dia. 4,375 ft.-11 ft. dia.	1,200 ft.-11½ ft. riveted	600 ft.-12 ft. dia., lined	9,625 ft.
			4½ miles

TABLE NO. 5. DATA ON RECENT LOW HEAD PLANTS.

Under 200 feet (61 m.). All turbines. Generators 3000 kw. or over.

No.	Power Co., Location, State and Year	(a) Present Installed kw. (b) Total Future Available kw.	Size and Number of Generators	Size, Type and Number of Water Wheels to a Generator	Head T.=Total E.=Effective Feet	Meters	Remarks
1	Wash. W. P. Co., Little Falls, 1910	(a) 20,000 (b) 20,000	4-5,000 kw.	1-9,000 hp. Twin runner turbine	T. E. 66	20.1	Dam and short Penstock
2	Wash. W. P. Co., Long Lake, 1915	(a) 27,800 (b) 50,000	2-13,900 kw.	22,500 hp. Twin runner turbine	E. 168	51.2	Dam and short Penstock
3	Spokane & In. Emp. Ry. Co., Nine Mile, 1907	(a) 7,500 (b) 15,000	2-3,750 kv-a.	4 turbines in pairs 6,850 hp.	E. 58	17.7	Power house part of dam
4	Grt. North. Ry., Tumwater, Wash., 1909	(a) 9,000 (b) 9,000	3-3,000 kw.	Sing. runner turbine 4,000 hp.	E. 200	61.0	11,870 ft. Penstock
5	Portld. Ry. Lt. & P. Co., River Mill, Nov., 1911	(a) 9,900	3-3,300 kw.	6,000 hp. turbines	E. 81	24.7	Power house part of Amburson dam
6	No. West. Elec. Co., White Salmon R., Wash., 1913	(a) 12,000	2-6,000 kw.	2-4,500 hp. Sing. runner turbines	E. 160	48.7	5,070 feet Penstock
7	Utah P. & Lt. Co., Oneida, Utah	(a) 20,000	2-12,222 kv-a.	15,000 hp. Sing. runner turbines	E. 140	42.7	
8	Grt. Falls W. P. & T. Co., Rainbow Falls, Mont., July, 1910	(a) 21,000	6-3,500 kw.	Twin runner 6,000 hp.	E. 105	32.0	2,350 ft. Conduit 8 Penstocks
9	Central Colo. P. Co., Shoshone 1909	(a) 10,000	2-5,000 kw.	9,000 hp. Sing. runner turbine	E. 170	51.8	

10	United Mo. Riv. P. Co., Capital City, Mo., 1911	(a) 35,000	7-5,000 kw.	8,800 hp. Twin runner turbine	E. 114	34.8	Power house below dam
11	Miss. P. Co., Keokuk, Ia., 1913	(a) 112,500 (b) 225,000	15-7,500 kw.	10,000 hp. Sing. runner turbine	E. 32	9.8	Power house built in dam
12	Southern P. Co., Ninety-Nine Is., S. C., 1910	(a) 18,000	6-3,000 kw.	5,200 hp. Twin runner turbine	E. 72	22.0	Dam and short pipes
13	Grand Rapids-Muskegon P. Co., Mich., 1907	(a) 10,000			E. 40	12.2	Power house built in dam
14	Southern P. Co., Rocky Cr. Sta., 1909	(a) 24,000	8-3,000 kw.	5,200 hp. Twin runner turbine	E. 63	19.2	Power house built in dam
15	Southern P. Co., Grt. Falls, S. C., 1907	(a) 24,000	8-3,000 kw.	5,200 hp. Twin runner turbine	E. 72	22.0	Dam and power house
16	Chat.-Tenn. Riv. P. Co., Hales Bar, Tenn., 1907	(a) 44,000 (b) 56,000	11-4,000 kw.	3-Runner turbines	E. 39.5	12.0	Power house built in dam
17	E. Tenn. P. Co., Ocoee R. No. 1, Tenn., 1912	(a) 15,000	4-3,750 kv-a.	Twin runner 5,400 hp. turbine	E. 98	29.9	Power house built in dam
18	Cen. Ga. P. Co., Ocmulgee R., Lloyd Shoals, 1909	(a) 12,000 (b) 18,000	4-3,000 kw.	5,500 hp. Twin runner turbine	E. 100	30.5	Power house built in dam
19	Alabama P. Co., Coosa Lock, No. 12, 1914	(a) 52,000 (b) 78,000	4-13,500 kv-a.	17,500 hp. Sing. runner turbine	E. 68	20.8	Power house built in dam
20	Appalachian P. Co., Devel. No. 2, Va., 1913	(a) 16,000	4-4,000 kw.	6,000 hp. Sing. runner turbine	E. 49	15.0	Power house built in dam
21	Pa. W. & P. Co., Holtwood, Pa., 1910	(a) 72,500 (b) 92,500	3-7,500 kw. 5-10,000 kw.	2-Runner turbine 1-Runner turbine	E. 53	16.1	Power house built in dam

TABLE NO. 5. DATA ON RECENT LOW HEAD PLANTS.—Continued.

Under 200 feet (61 m.). All turbines. Generators 3000 kw. or over.

No.	Power Co., Location, State and Year	(a) Present Installed kw. (b) Total Future Available kw.	Size and Number of Generators	Size, Type and Number of Water Wheels to a Generator	Head T.=Total E.=Effective Feet	Meters	Remarks
22	Schenectady P. Co., Schaghticoke, N. Y., 1908	(a) 12,000	4-3,000 kw.	5,000 hp. Sing. runner turbine	T. 152 E. 146	44.5	½ mi. canal; 850 ft. Conduit; Penstks.
23	Niag. Falls P. Co., Plant No. 1, 1895-1913	(a) 37,500 (b) 37,500	10-3,750 kw.	Sing. runner 5,500 hp. turbine	E. 156	47.5	Canal and Forebay
24	Niag. Falls P. Co., Plant No. 2, 1902	(a) 41,000 (b) 41,000	11-3,750 kw.	Sing. runner 5,500 hp. turbine	E. 156	47.5	Canal and Forebay
25	Ont. P. Co., Niag. Falls, N. Y., 1902-14	(b) 165,000	7,500 kw. 4-10,000 kw.	12,000 hp. turbine 15,000 hp. turbine	E. 175	53.4	6,500 ft. Conduit
26	Canadian Niag. P. Co., 1902-05	(a) 78,800 (b) 175,000	7-7,500 kw. 3-8,776 kw.	10,000 hp. Sing. runner turbine	T. 136 E. 130	39.7	Forebay
27	Elec. Dev. Co., Niag. Falls, Canada	(a) 62,000 (b) 93,500	4-8,000 kw. 3-10,000 kw.	15,000 hp. Sing. runner turbine	E. 143	43.6	Forebay
28	Laurentide P. Co., Grand Mere, P. Q., 1913	(a) 75,000 (b) 125,000	6-12,500 kw.	1-20,000 hp. Sing. runner turbine	E. 76	23.2	
29	Cedars Rap. M. & P. Co., Cedars, P. Q., 1914	(a) 90,000 (b) 120,000	10,000 kv-a.	10,800 hp. Sing. runner turbine	E. 30	9.2	Headrace
30	Canadian L. & P. Co., St. Timothee, Que., 1912-15	(a) 20,000 (b) 53,000	5,000 kv-a.	Twin runner 7,200 hp. turbine	E. 48	14.6	Power house built in dam

31	Shawinigan Fls. W. & P. Co., St. Maurice R., Que., 1912	(a) 60,000 (b) 60,000	5-12,000 kv-a.	18,500 hp. Twin runner turbine	E. 145	44.2	600 ft. Penstocks
32	Winnipeg Mun., Canada, 1911	(a) 15,000 (b) 47,000	5-3,000 kw.	Twin runner turbine, 5,200 hp.	E. 45	13.7	Dam and Forebay
33	W. Kootenay P. & L. Co.,	(a) 9,000 (b) 18,000	2-4,500 kw.	3-Runner Twin 8,000 hp. turbine	E. 72	22.0	Power house built in dam
34	W. Can. P. Co., Stave Falls, Jan. 1, 1912	(a) 20,000 (b) 40,000	2-10,000 kw.	1 turbine	T. 125	38.1	Dam and short Penstocks
35	Norwegian H.-E. Nitrogen Co., Svalgfos, Norway, 1909	(a) 42,000	4-10,500 kw.	2-runner turbines	E. 161	49.0	Penstocks
36	Trollhätten, Sweden, 1911	(a) 40,000* (b) 80,000*	4-10,000 hp.	Twin runner 12,500 hp.	E. 100	30.5	4,000 ft. Canal
37	Tajo R., Madrid, Spain, 1910	(a) 15,000* (b) 30,000*	4-3,500 hp.	Twin runner turbines	E. 109	33.2	
38	Seros, Spain	(a) 40,000 (b) 50,000	4-10,000 kw.	1-16,000 hp. Sing. runner turbine	E. 162.5	49.8	Short Penstock from dam
39	Ventavon, France, 1910	(a) 18,000 (b) 27,000	4-4,500 kw.	Twin runner 6,200 hp. turbine	E. 164	50.0	

* Horsepower.

DISCUSSION

Mr. Doble.

Mr. W. A. Doble,* M. Am. Soc. C. E. (by letter), observed, in reference to penstocks, that the principal question involved is whether the penstock should be made of plate-riveted construction, or lapwelded. The determining factors in this connection must be the ultimate cost and the results; and one of the important factors to be considered is the frictional retardation of the flow of water due to riveting or butt-strap joints.

In pipe lines subjected to a moderate head, and where the diameter is comparatively large in proportion to the thickness, it generally works out that some form of riveted pipe is the cheapest to install. In high-heads plants, however, this is not usually the case. The lapwelded tube, having the first great advantage of a smooth interior surface, secures much lower frictional losses, and therefore to produce equal results, a smaller diameter of pipe line can be used, which in turn allows thinner metal to be used in the walls with the same factor of safety; these results being cumulative, permit a smaller and lighter pipe.

Among the examples noted, Mr. Galloway refers to the pipe line in Boulder Canyon, Colorado, which operates under a head of 1,830 feet (558 meters), length 9,800 feet (2,990 m.), being riveted throughout, the diameter varying from 56½ inches (1,435 mm.) at the top, to 44 inches (1,117 mm.) at the bottom, with a plate thickness of 1¾ inches (44.5 mm.).

The making of this pipe line of plate construction was a mistake, as was shown by the excessive first cost due to the difficulties of endeavoring to fabricate a pipe line of 44 inches (1,117 mm.) diameter, with a plate thickness of 1¾ inches (44.5 mm.). Engineers having experience with the difficulty of forming heavy plates on such a small diameter as this, and forming the heavy inside and outside butt straps and connecting joints, will appreciate this.

The makers found great difficulty in manufacturing this pipe line. The time required was much greater than they anticipated, and the starting of the power plant was seriously delayed. In addition, when the pipe line was installed, it was practically a failure for the reason that nearly every joint leaked badly. It was found impossible to caulk these joints, and it finally became necessary to weld all of the seams and joints for the lower part of the pipe line. This took a considerable length of time, and involved a very great expense, approximating from 35% to 50% of the original cost of the pipe. It is therefore questionable as to whether this line can be considered as a successful example of riveted-pipe construction, especially as its defects were corrected by oxy-acetylene welding. Had the engineers adopted the metallic-electrode electric system of welding, this could have been performed in less time, and with a considerable saving in cost.

* Chief Engr., Pelton Water Wheel Co., San Francisco, Calif.

Regarding the general question of the use of the two types of pipe line, with the exception of the Pacific Coast, the lapwelded type is strongly favored by engineers, as it is indeed by many of the power plant engineers of the Pacific Coast. However, having investigated the subject he had ascertained that in all of the pipe lines installed, where welded pipe was used, there have been five reports of defective welds, and these results have led some engineers to condemn the lapwelded pipe as being uncertain. He felt, however, that the experience with the Boulder pipe, as a single example of defective riveted pipe construction, would many times offset the defective welds in all of the welded pipes that he had been able to find reported. He considered the criticism, therefore, hardly justified. Mr. Doble.

Mr. Doble further pointed out that his purpose in citing the Boulder pipe is, that unless the troubles experienced with this pipe line were made of record in this paper, engineers might otherwise accept it as a safe precedent to follow.

Further, in these five reported complaints of defective welding, in most cases it was only one or two comparatively short defects, which were insignificant when compared with the total amount of lapwelded pipe lines that have been installed. As an illustration, the following figures give the amount of welded pipe lines furnished by one maker, the figures representing the output for 1913, which was the date of the last report.

Number of pipe lines—170.
Total length—366,917 ft. (111,865 m.).
Maximum pipe diameter—84″ (2,134 mm.).
Minimum pipe diameter—11″ (277 mm.).
Max. thickness of plates—1⅛″ (28.6 mm.).
Min. thickness of plates—3/16″ (5 mm.).

It will be seen that the amount of this type of pipe line used has been very great, and in considering the questions of reported defects, the extensive use of this type of pipe line should be considered.

A further advantage in the installation of the welded pipe line is in the great saving in time in the laying and finishing of the pipe line in the trench.

In the welded pipe lines thus far installed on the Pacific Coast, the pipe has been welded from a plate of steel of the proper thickness. However, this is not the best form for the heaviest pressure work, such as the Boulder Canyon, Colorado, plant, or the pipe line for the Pacific Coast Light & Power Corporation at Big Creek. For this high-head work, the design which should be used consists of a comparatively thin barrel, or tube, reinforced with seamless rolled steel bands shrunk on the outside of the pipe tube, similar to the construction adopted for large guns and mortars. A comparatively thin plate can thus be used, which insures a safe welding, and provides a material to take up the

Mr. Doble. stress in the pipe, which can be made of very high elastic limit. Such material being available, at a reasonable cost, ranging from 125,000 pounds tensile strength per square inch to 160,000 pounds per square inch, and having an elastic limit as high as 100,000 pounds.

In such a pipe, the bands are shrunk on the pipe tube and are designed of the size and cross-sectional area required to carry the stress in the pipe. The spacing of these bands is such as to provide for the proper support to the pipe tube. In general, it is found that the bands can be spaced about the width of the band apart; but, necessarily, each design of pipe must be worked out to meet the conditions under which it is to operate. Such a pipe line represents the best possible construction at reasonable cost.

In certain of these high pressure pipe lines, a seamless drawn pipe tube has been used; but owing to the limitations of this process, the length of each section, or drawn tube, is comparatively short, making it necessary to weld these short sections, thus adding to the high cost of the process.

In the construction of the pipe line for the Mill Creek No. 3 Plant of the Southern California Edison Co., operating under 1,960 feet head, a welded pipe was used, but the lower end of this pipe was reinforced by being wire wound. This pipe has been in continuous service since 1903, but the cost of this process is greater than the banded pipe, and there is more liability of corrosion of the wires. The banded pipe represents the better type of construction.

The manufacture of lapwelded pipe has increased very rapidly. There are now four companies in the United States, seven in Germany, at least one in England, and one in Sweden, equipped to manufacture this class of pipe.

In addition to the types of joints specified by Mr. Galloway, Mr. Doble pointed out that a form of joint termed the "Muff" joint is also extensively used. This method provides an expansion joint for each pipe length of the line, one end of each section of pipe being belled out to receive the straight end of the adjoining section, and this joint is packed with a special composition held in place either by lead caulked into the bell, or by a follower. It also permits of very rapid installation.

Mr. Galloway recommends as the best method of installing pipes, the supporting of these pipes on concrete piers located from 15 feet to 20 feet (5 to 7 m.) apart, and anchored at intervals by steel straps. Such a construction is used in a great many cases, but unless a "Muff" type of joint is used, or a large number of expansion joints, there is danger of expansion and contraction stresses, especially during the installation of the pipe, and also at any time the pipe line should be emptied. Further, with such a construction, the pipe line is not as well supported as where it is bedded directly in the earth, first having been thoroughly protected against erosion and corrosion, and then tamped and entirely covered.

In his opinion, the best practice in pipe line installation is to first locate the heavy pipe connections and thrust block located at the power plant, providing substantial concrete or stone supports to prevent any slippage or creeping of the pipe lines. After these terminal connections at the power plant are ready, then the pipe line should be installed in sections of approximately ten lengths, or any convenient number. When these lengths have been jointed, a test flange should be put on at the upper end, the pipe filled with water and brought up to test pressure, and when found tight at all joints should be then thoroughly tamped, back-filled and covered; then the test head should be removed and the next series of ten sections installed, leaving the lower ten sections filled with water. This should be repeated until the entire pipe line is completed. Mr. Doble.

By this method the pipe can be tested as it is laid, tamped, back-filled and covered, and kept full of water, thus eliminating all expansion and contraction strains. It further has the advantage that due to keeping the weight of the water in the pipe, the pipe takes up any settlement as it is being laid, thus giving assurance against stresses in the pipe due to slight settling of the foundation.

The writer has known of one case where the pipe line was laid starting at two different points, and the daily creepage of the line, until the connecting section was put in, amounted to seven inches, this being the actual daily travel of the pipe—closing the connecting point when hot in the daytime and opening out that far after cooling down at night. There have been other interesting examples of pipe lines being pulled in two due to having been installed in warm weather, and later subjected to the internal stress due to the shrinkage of the plates in cold weather.

It is of the utmost importance in installing heavy-pressure pipe lines, especially on steep side hills, to most thoroughly anchor the pipe line, protecting it against slippage, and further, protecting the foundations against undermining during heavy rain storms.

Regarding protection against corrosion, lapwelded pipe has an advantage over riveted pipe, due to the process of manufacture. In the riveted pipe the plates are made by the plate mill, shipped to the pipemaker and fabricated, the original rolling mill scale being left on the plates. During transportation and manufacture previous to dipping, some rusting is very apt to take place; whereas, in the process of manufacturing the welded pipe, after the pipe tube has been welded, it is then placed in the annealing furnace, brought up to a proper annealing heat, passed through the rounding-up rolls, and while still hot and before there is any chance for mill scale to form or oxidation to take place, it is first scrubbed all over with steel brushes, and then given the first treatment of protective coating, put on at such a high heat that it also protects the pipe against rusting during fabrication and before taking the final dipping.

Mr. Doble. In addition to this method, many pipe lines are now being protected by wrapping them with one or more layers of special, heavy burlap bands. This burlap banding is wound spirally around the pipe, and while being wound is cemented to the pipe by being saturated with a protective pitch, the band being drawn through a heated pitch receptacle while being wound on the pipe. This makes the best possible protection, and protects the initial coating and dipping. The pipe can then be buried in the earth at a depth below the frost line, insuring against expansion and contraction stresses, as well as the corrosion and mechanical injuries to which pipes placed on, or above, the surface are exposed, as frequently the protective coating is knocked off by men walking on the pipe, or other causes which start local corrosion.

Under the head of valves and accessories, Mr. Galloway refers to the use of hydraulic cylinders, or electric motors, for operating gate valves. Mr. Doble stated that in their latest practice, they were substituting, in lieu of these devices, a reversible water motor. This has a great advantage over a hydraulic cylinder, as the cylinder and also the packing of the piston in the latter are subject to deterioration from impurities in the water; also, there is a tendency for silt to deposit in the cylinder and valves, preventing the operation of the latter.

The reversible water wheel has also the advantage of an extremely high starting torque, enabling it to overcome the tendency of the valve disc to adhere to its seat after remaining closed for some time.

A very important element which Mr. Galloway has not mentioned, is the construction of the head gates. In the earlier days very simple forms of wooden head gates were used; but the importance of this element is now being appreciated, and in the most recent work, head gates of the needle type, hydraulically operated, have been installed with complete success; these valves have the advantage of absolute certainty of operation.

Referring to the choice of power units, Mr. Doble pointed out that the choice between a "Francis" type turbine or a "Pelton" wheel depends on somewhat broader considerations than as outlined by Mr. Galloway. The lines of demarkation are not as well defined as might be understood from the paper, and, therefore, each installation must be thoroughly investigated, considering not only the question of horsepower and speed of wheel, but also the cost of the foundations, pipe connections and the character of the water.

In a recent plant consisting of six units, 850 k.v.a. capacity, under an effective head of 107 ft., where it would appear that the "Francis" type turbine would be most suitable, it was found absolutely necessary to install vertical shaft "Pelton" units. The reason for this was that the character of water furnished to the plant carried excessive quantities of grit and silt, so that the probably excessive deterioration of the Francis turbine precluded consideration of this type. The units, which rotate at ninety-four revolutions per minute, are arranged with

a vertical shaft, six jets of water being applied to the wheel. These units have recently been put in service and preliminary tests indicate an efficiency of approximately 84%. In general, the greater horsepower of the unit permits the satisfactory installation of the Francis turbine under higher heads, but this is limited by the character of the water furnished to the plant. Mr. Doble.

This is of the utmost importance, particularly in mountain sections where high heads are available, for the reason that in such countries the water at certain seasons of the year is apt to carry large quantities of sand and silt due to heavy rains in the mountains, and very much increased by the disintegration of the country rock, due to freezing and thawing. In certain sections of the Pacific Coast, each spring brings down huge quantities of decomposed granite and mica. Material of this kind is very erosive and rapidly cuts out the revolving elements and clearance rings of the turbine.

Referring to efficiency, Mr. Doble observed that the initial efficiency of a water wheel is not as important as the question of the maintained efficiency, and in many plants it is better engineering to consider primarily the question of sustained efficiency and cost of upkeep and continuity of service. In other streams of the Pacific Coast, where the water comes from countries heavily timbered and with heavy vegetable growth, the water at all times is non-erosive, and on such streams turbines can be installed under much higher head with reasonable prediction of satisfactory, reliable service.

Regarding multiple nozzles, he called attention to the fact that this question dates back to the very earliest history of the development of the Pelton wheel in California. It was the practice in the early days to use two, three and four nozzles on a single wheel, thus permitting smaller diameter jets, smaller buckets and cheaper wheel construction. As to whether a single jet or multiple jets are to be used on a wheel, depends entirely upon conditions existing at the power plant; also, on the operating conditions, the cost of the generator, the difficulties of transport of larger and heavier machines in mountainous countries, and on the character of the load. In some cases, owing to long periods of operation at half load or less, multiple jets are advantageous.

In general, however, all things being equal, a horizontal-shaft single-jet unit is the simplest, most efficient and the best type of unit to install, particularly as it simplifies the question of heavy pipe fittings.

These remarks are also true as between the selection of a horizontal-shaft and vertical-shaft unit. Usually the increased cost of foundations and piping for the vertical shaft unit makes the final cost of the power plant more expensive. This question is therefore one that must be answered only after a thorough analysis of all the conditions.

With reference to the preference as between horizontal and vertical-shaft small-unit turbines, the horizontal-shaft type is more favorable. This is also true under special conditions for large Francis turbines;

Mr. Doble. but, in general, it is preferable to install large size Francis turbines of vertical-shaft construction, thus bringing about ideal conditions from the turbine standpoint.

Prof. Marx. **Prof. G. H. Marx,*** Mem. Am. Soc. M. E., expressed his regret that Mr. Galloway had seen fit to impute obstructionist motives to the men in the Government service who are devoted to safeguarding the property rights of the general public against monopolistic exploitation.

Mr. Galloway. **Mr. J. D. Galloway,†** M. Am. Soc. C. E. (author's closure), called attention to the fact that in writing the paper on "Hydraulic Power Development and Use", he had endeavored to adhere to the instructions of the Committee in charge. As understood, the paper was limited to a discussion of present practice, without particular comment upon the merits of any one type of construction.

He noted, however, that Mr. Doble, in his discussion, had entered into the subject of the design of riveted pipes. The subject is one of considerable interest, where much difference of opinion exists. It is unnecessary to refer to the smaller amount of friction in a welded pipe as compared to that of a riveted pipe. The merits of the two types of construction must be determined by other controlling factors, the principal one of which is the service in the field. Mr. Doble had referred to the pipe line of Boulder Canyon, Colorado, as an example of a riveted pipe line which failed in service. The failure of this pipe line had nothing whatever to do with the merits of riveted pipe. Anyone conversant with the proper design of such pipes could have foreseen the leakage which actually occurred in this pipe, due entirely to defective design. It must be recognized that any type of construction necessarily requires proper design of its parts. When this proper design is lacking, there is no reflection upon the type as a whole. The Boulder pipe did not fail through failure of riveted joints. It leaked because the joints were not properly designed to be water-tight. Aside from this, he did not know of any riveted pipe line which has failed in service through failure of the riveted joints. He is, however, familiar with a large number of such pipe lines, working under high heads, which have given satisfaction for many years.

Referring to the subject of welded pipes, he is also familiar with a number of installations where lap-welded pipes have been used and in which a number of disastrous failures have occurred. He has also information regarding such failures on pipe lines in other places. The general method of failure is for these pipes to open on the weld, tear back a large section of the pipe and allow the water to escape, to the extreme damage of the power house below. Such failures have been noted in lap-welded pipes of both foreign and domestic make.

Mr. Doble also refers to the support of pipe lines on concrete piers. His opinion is well taken, in that it is always best to bury such pipe

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† Cons. Engr., San Francisco, Calif.

Mr. Galloway.

in earth, if possible. This forms the best anchorage for any pipe. There are, however, a number of cases where the hillside is so steep that burying the pipe in earth is impossible. It was with such installations in mind, that reference was made to support by means of concrete piers.

Referring to Mr. Doble's comments on the design of water wheels, this subject is covered in other papers before the Congress, and therefore no further comment seems necessary here.

Paper No. 147

DEVELOPMENTS IN MODERN WATER TURBINE PRACTICE.

By

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PREFACE.

I shall deal with the modern practice in water turbines, dividing the subject into three sections, low-, medium-, and high-head water turbines, and afterwards speak of the automatic governors. Discussing the matter chronologically, I intend to explain the final object to be attained, and the means of doing so, proposed and employed up to now. The latest developments will be discussed in detail. I am in a position to do so, as Switzerland affords the desired facilities for installing low-, medium-, and high-head water turbine plants. The principal features of the development of this modern science have been tried in this country, and adopted on a much larger scale abroad. This paper will be divided into four chapters, and will give at the end an idea of the present outlook for the near future.*

LOW-HEAD WATER-POWER DEVELOPMENTS.

The first large low-head water-power plants in Switzerland were laid out at Rheinfelden, on the Rhine, about 30 kilometers upstream from Basel, where twenty vertical turbines of

* The paper by Dr. Zoelly was accompanied by a large number of photographs and drawings, of which only a few could be reproduced on account of lack of space.—Editors.

900 hp. each were installed in the year 1894, and another installation, at Chèvres, with fifteen turbines of 1200 hp. each, built in the same year, located some 5 kilometers downstream from Geneva on the Rhone. The power developed by both plants is partially used for lighting and power, and partially in chemical works located near them. With a view to obtaining as high a speed as possible on the shaft, in order to use generators of a light and inexpensive type, the designer was induced to arrange quadruple turbines at Rheinfelden and double turbines at Chèvres, each runner containing three different rows of moving blades. The runners were designed of the conical type, and are controlled by hydraulically operated gates. The revolving weight of the units, in both plants, is supported by a thrust bearing running with a film of oil under pressure. The speed attained in both plants is rather low in proportion to the head. The output of each generator set is also very small, which increases the initial cost of the installation in a very serious manner. The tendency toward increase of speed, with still larger outputs, and the desire to avoid any generators not of standard design, inaugurated the era of installations with horizontal turbines only, at the beginning of this century. It must be borne in mind, that at this early date the vertical-shaft generator was exceptional. The first larger plant of this kind was the one for the development of the water power of the Aare, at Wangen, containing seven quadruple turbines of 1500 hp. each, built in 1904. The municipal plant of the City of Berne, also on the Aare, at Felsenau, containing five twin units of 1250 hp. each, was started in 1907. Two very large developments, one on the Rhine at Augst, some fifteen kilometers upstream from Basel, and the other at Laufenburg, about fifty kilometers upstream from the same city (Fig. 1), were equipped with horizontal quadruple turbines with inspection chambers for the bearings, accessible from underneath. These installations are all equipped with standard horizontal generators, the whole controlling mechanism of the turbine being under water in the open chamber directly connected to the head race. The elevation of the shaft above the tail race is determined by the maximum draught head of the water turbines, and the generator room floor is overflowed during floods, so that a number

of precautions had to be taken in the construction of the plant to avoid any injury to it.

Very great progress has been made, especially with a view of avoiding this trouble, by raising the level of the turbine to nearly the level of the head race, or even above the latter. Some important plants have been built on these lines, with very great success. The Amperwerke Company started in 1908 the Unterbruck Power Station, with three quadruple horizontal turbines of 650 hp. each, and the Kranzberg plant, with

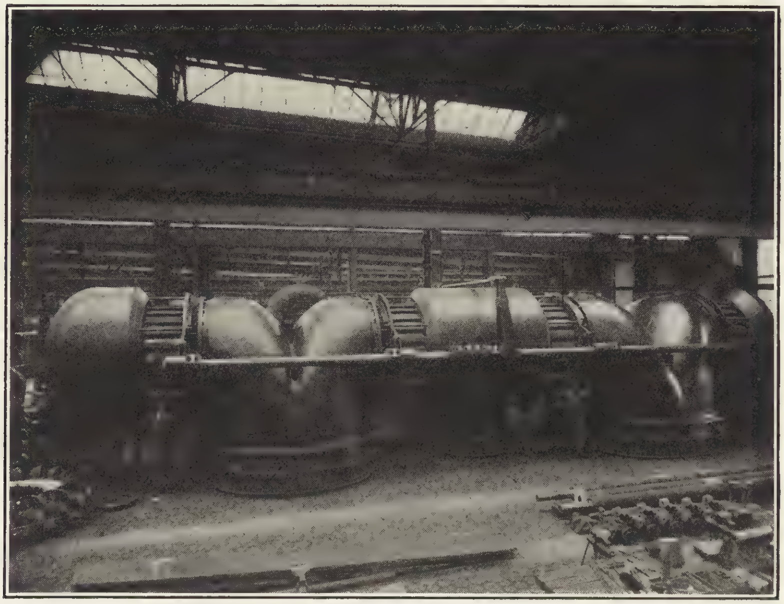


Fig. 1. Quadruple Horizontal Turbine at the Plant at Laufenburg, Switzerland.

$H = 8$ m.; $N = 7500$ hp.; $n = 107$

three quadruple horizontal turbines of 950 hp. each. Both plants were ready for operation in 1908. Another very interesting installation of quadruple turbines is that of Messrs. Jenny and Schindler at Kennelbach in Austria, with one quadruple horizontal turbine of 250 hp., built in 1910, with only two bearings. All these plants are designed in such a manner that the turbine starts as soon as the gate is opened, the highest point of the runner being not higher than the head-race level.

The plant of Messrs. Günther & Richter, in Germany, contains a sextuple horizontal turbine installed above the head-race level, so that a starting device is necessary to set the turbine in motion. By opening a small valve, water from the head race is discharged into the draught tube of the turbine; the water acts as an ejector, producing very quickly the necessary back pressure in the turbine chamber to permit the admission of sufficient water to drive the turbine. The time necessary for doing so is only two or three minutes. The high elevation of the shaft permitted the direct coupling of the grinders to the turbine and avoided all losses due to any kind of transmission gear which would have been necessary if the water turbine had been installed according to the usual practice.

All these water turbines have the disadvantage of exposing the whole controlling mechanism to rather severe wear, as it must work under water. Twin and quadruple turbines are rather complicated machines, which require a correspondingly large number of spare parts, and they do not ensure much saving in the operating costs. The ideal turbine is one of simple design which will permit the controlling mechanism to be located out of the water. The first improvement to be attained was the increasing of the specific velocity of single-runner turbines of higher outputs to a sufficiently high speed to permit of the direct coupling of the turbine with the generator. These studies began about 1910. Each of the large plants at Keokuk on the Mississippi and Cedar Rapids on the St. Lawrence fulfils these conditions. The same design has been adopted for the power station at Olten-Gösgen, with a head of sixteen metres and five units of 10,000 hp. each, running at 93 revs. per minute, and for two additional units to be installed in the near future. The large plant for Eglisau on the Rhine, the installation of which is just now being seriously discussed, will very probably contain seven 6000 hp. units of the vertical single-runner type, although the first proposition, made some six years ago, provided for horizontal quadruple-runner turbines. These installations with vertical turbines permit the generator to be placed at such an elevation above the tail-race level that the flooding of the generator room, even at very high water, can be avoided.

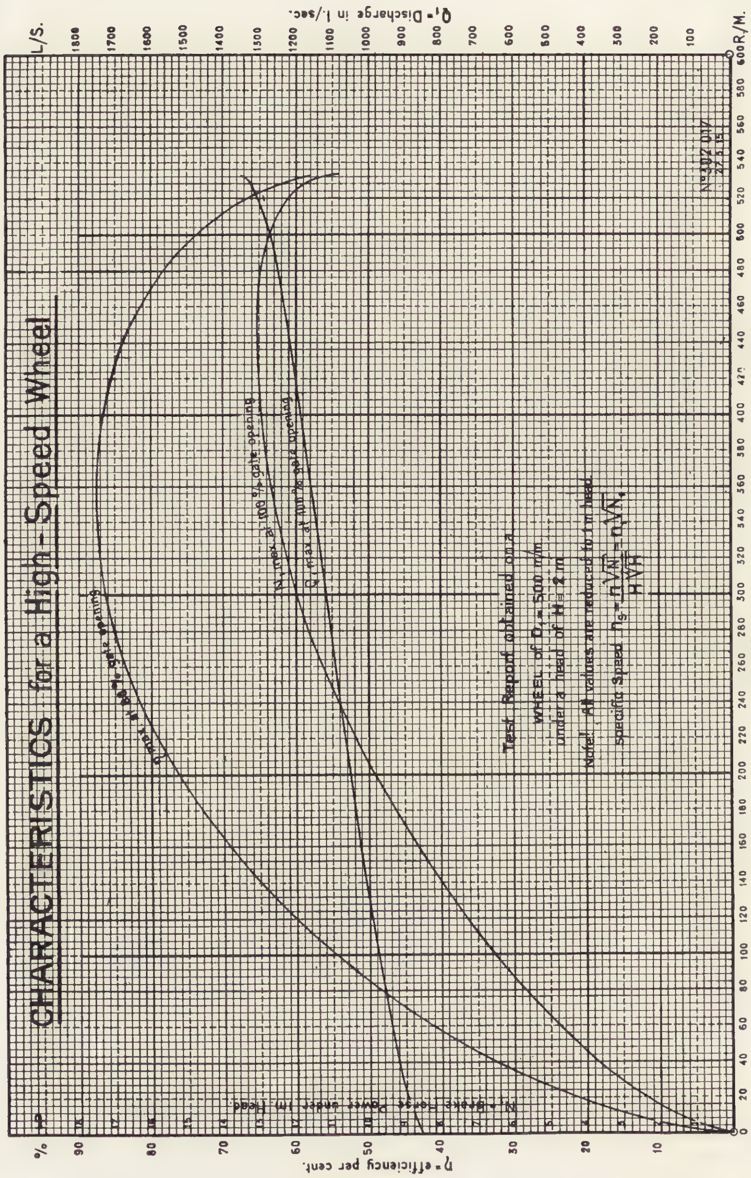


Fig. 2. Characteristics of a High-Speed Turbine.

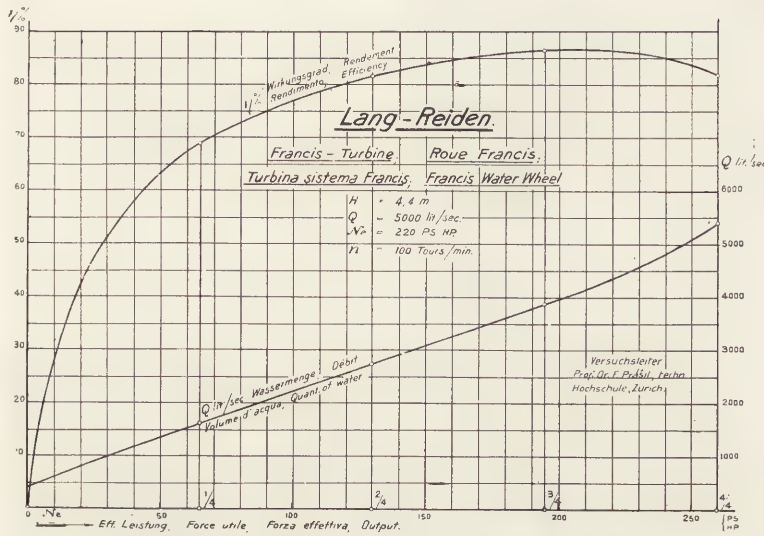


Fig. 3. Performance Curves of a Low-Head Turbine.

It is obvious that one of the main difficulties in designing low-head turbines is to arrange them for a sufficient capacity, especially with the smallest heads, that is, during floods. This condition ought to be fulfilled without interfering at all with the very best efficiency during the low-water periods, corresponding to the high heads, with which the runner has to work. The enclosed diagram, Fig. 2, may give an idea of the perfect manner in which combinations of both conditions have been attained. I am sure that this new and very simple design will meet with increasing favour as time goes on, and become the standard for this type of water power development. Fig. 3 shows the performance of a standard modern low-head turbine as to efficiency and discharge in respect to the output.

MEDIUM-HEAD DEVELOPMENTS.

The controlling mechanism of the guide vanes of the spiral Francis turbines, which are the water wheels most used for medium pressure, originally was always in the water. All the levers, links, pins, and so on, were constantly exposed to the water stream and all its impurities. A very important installation put down with controlling mechanism of this type

is the Brillanne Power House in the South of France, with five horizontal twin turbines, in spiral casings, of 3500 hp., started in 1906. The advantage of the external regulating device is so great that these large turbines were changed in 1911 to this new design. Other very interesting twin turbines (of 7000 hp.) of the same design, with vertical shafts and spiral casings, are running at 128 revs. per minute under a head of 19 metres in Messrs. Kellner Partington's installation in Norway. In the

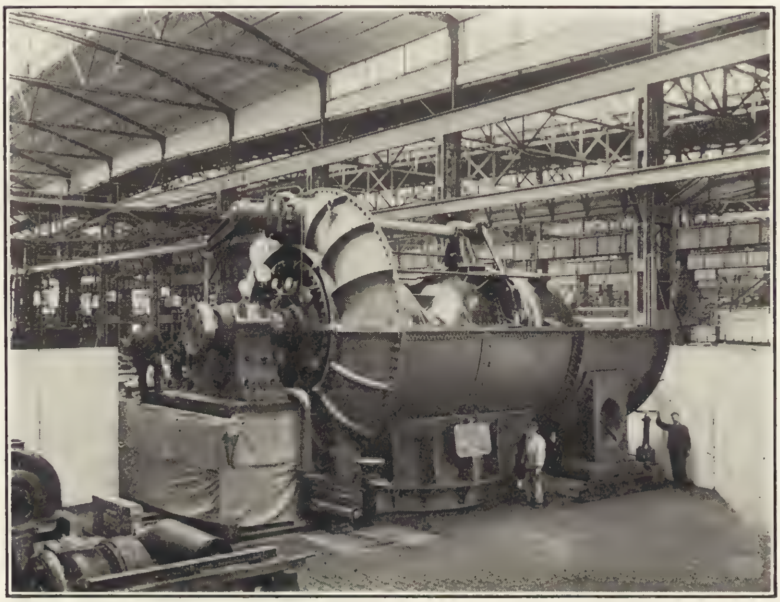


Fig. 4. Twin Horizontal Francis Turbines; Stave Lake Power Plant, Vancouver, B. C.

$H = 35$ m.; $N = 13{,}500$ hp.; $n = 225$

case of turbines of high power, large water capacities and very short penstocks, the turbines are arranged with advantage, not in spiral, but in cylindrical casings, as the ground floor space necessary for their installation is thus very much reduced as compared with that for spiral turbines. All of these turbines are designed with the controlling mechanism in the water, and though it is not absolutely impossible to arrange the mechanism outside of the casing, this is not generally done, owing to the

much higher cost. The first power station at Shawinigan, of the Montreal Power & Light Co., includes some turbines of this type, developing 10,000 hp. each. As water power plants with 30 to 40 metres head are very frequent in Canada, there are some very interesting installations in that country, for instance, the power plant of the Western Canada Power Co. at Stave Lake, where there are four horizontal twin turbines installed in cylindrical casings, developing 13,500 hp. each, under a head of 35 metres (see Plate I and Fig. 4). Eight turbines of the same design, of 4500 hp. each, are installed at the Sao Paolo Power Plant in Brazil. I should further like to mention the plant at Healy Falls, with two similar turbines of 5600 hp. each.

The increasing heads for which Francis turbines have been designed require quite another kind of controlling mechanism, and medium pressure turbines had first to be provided with external regulating devices. Each guide vane is made in one piece with its pin, the latter extending outside the casing through stuffing boxes. All the levers are fixed on the pins and controlled by the servomotor by means of a special device consisting of rings and rods placed outside the casing. This arrangement offers great accessibility to the working parts which can be well lubricated, and also avoids any severe wear and tear. The large power plant at Chippis, on the Rhone, in Switzerland, contains large spiral Francis turbines of 7100 hp. running under a head of 75 metres. The Puntledge Power Station in Canada has two such turbines of equal dimensions, with an output of 6000 hp. each, under a head of 99 metres. Another important water-power development, belonging to the Mexican Northern Power Co., on the Rio Conchos in Mexico, contains four twin spiral turbines of 9700 hp. each, which began running in 1911. The municipal plant of the City of Tokyo, in Japan, is working under a head of 120 metres, and is equipped with six horizontal twin spiral turbines of 17,500 hp. each (see Plate II). The Montjovet plant, in Northern Italy, containing three twin horizontal units of 6500 hp. each, under 50 metres head, has recently been put in running order.

This kind of turbine permits of increasing the speed as much as desired, in order to use the cheapest type of generator. About the year 1910, such improvements began to be seriously

taken up by the manufacturers. Very important results have been obtained in this direction with a new arrangement, that is to say, with an overhung runner-wheel mounted on the end of the generator shaft. As the whole of the controlling mechanism can be located on the cover of the turbine, and the draught tube bend designed to suit the shape of high-head runners, it is possible to materially increase the specific speed of the turbines without interfering, in any way, with the accessibility of the external controlling gear. The draught tube bend has no internal obstruction at all, such as shaft, stuffing box, etc., which is a very important point in regard to good efficiencies with high-speed runners. A very interesting plant, at Tuxpango in Mexico, contains two generator turbines of 9000 hp., running under a very high head of 170 metres, and shows in a convincing manner the marked importance of the new arrangements (see Plate III). The chief advantages are the very small floor space occupied, the inexpensive general design, and the splendid accessibility to all parts of the turbines and generators. It is possible to disconnect the twin turbines into two separate halves, each runner being connected at one end to the generator shaft, thus providing for a generating set with only two bearings. This arrangement has been chosen for the large turbines of the Tremp Power Station of the Barcelona Traction Light & Power Co. in Spain. Each of the four turbines installed is designed for a maximum output of 12,500 hp., running at variable heads of 40 to 70 metres. By dismantling the draught tube bends, it is very easy to remove the runners and change them. It is intended to have for this plant two sets of runners to suit the varying heads, in order to insure the best efficiency at all times.

The constant increase in size of the generating sets for turbines of medium head, from, say, 20,000 hp. upwards, has rendered it necessary to make serious investigations as to the possibility of installing vertical turbines instead of the horizontal ones, because the very large spiral casings in question are much easier to install in a horizontal position than vertically. As a matter of fact, the former arrangement is the only practicable one for units of about 40,000 to 50,000 hp. Very large dimensioned units have already been erected in the Seros Power

House, of the above mentioned company, in Spain, with single-runner spiral turbines, each of 15,000 hp., working under a head of 50 metres (see Plate IV, and Figs. 5 and 6). The spiral casing was first made of wrought iron and had a circular cross section, which type of construction proved very satisfactory. In fact, the whole turbine is fixed on a very heavy cast-steel ring, supporting, directly, the yoke and the thrust bearing. The scroll casing of sheet iron is also fixed to this ring but is not strained by any part of the weight of the turbine,

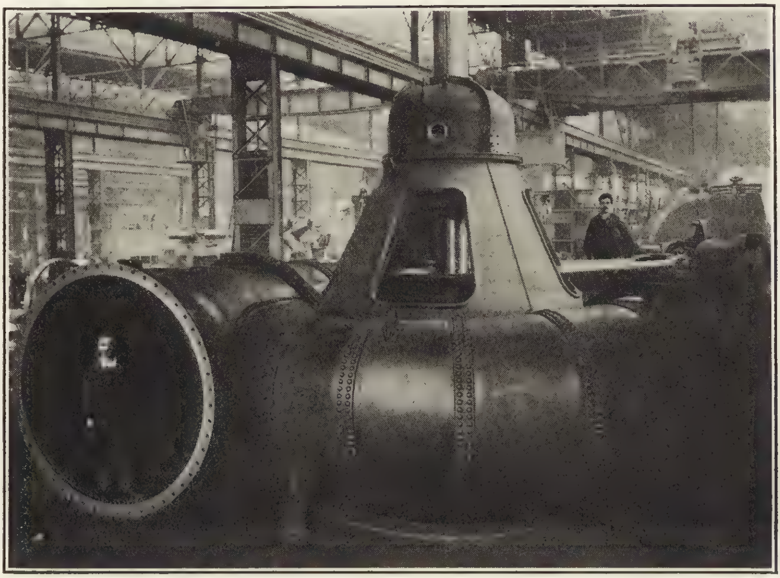


Fig. 5. Single Vertical Turbine in Wrought-iron Scroll Casing; Seros Plant, Spain.

H=50 m.; N=15,000 hp.; n=250

except by its own weight. This is the striking feature of the whole design. Scroll casing and turbine may be erected simultaneously in the shops. The very short time in which these casings can be made and their remarkably small weight are important advantages of the new design. The thrust bearing, which is, of course, a very important part of such a turbine, can be installed on the top of the generator or below it, supported on the turbine itself by means of yokes or any similar

part. This lay-out is the one which has most chances of becoming a standard one for turbines of medium head and very large outputs, and serious plans are already made for turbines of 50,000 to 80,000 hp. in one runner, with spiral casing of wrought iron, as is now being made. The runner is the most important thing to be designed in order to attain such enormous outputs as those just mentioned. The questions of excessive erosion by sand or corrosion due to impurities contained

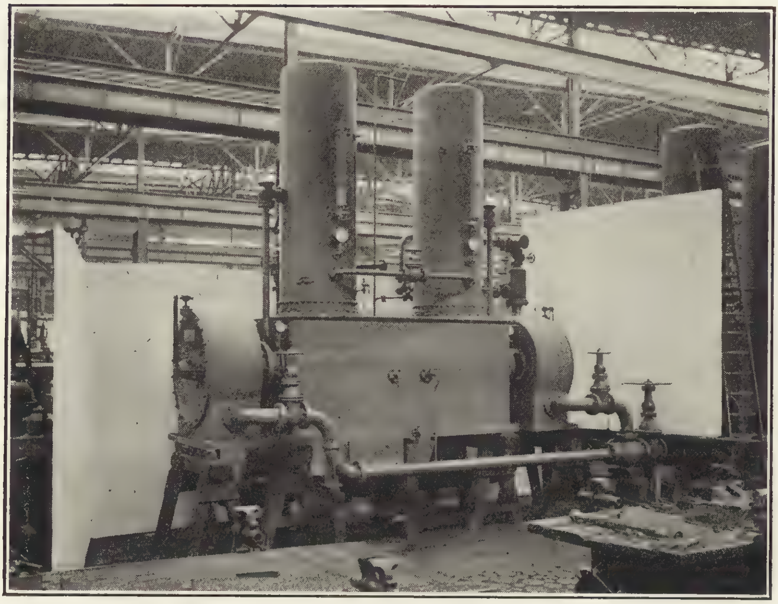


Fig. 6. Pumping Set with Driving Turbines; Seros Plant, Ebro Irrigation & Power Co., Spain.

in the water are also of the utmost significance. The designer increases his demands on the foundry and the machine shop, but the improved methods of the former and the very important improvements in the construction of the machines insure the possibility of meeting such requirements. It is a standard practice nowadays to provide medium-head runners with vanes of wrought iron, cast in steel rings and discs. The whole runner is generally made of cast steel, in one piece, for heads of 50 to 60 metres. Another difficulty to be considered is the transport

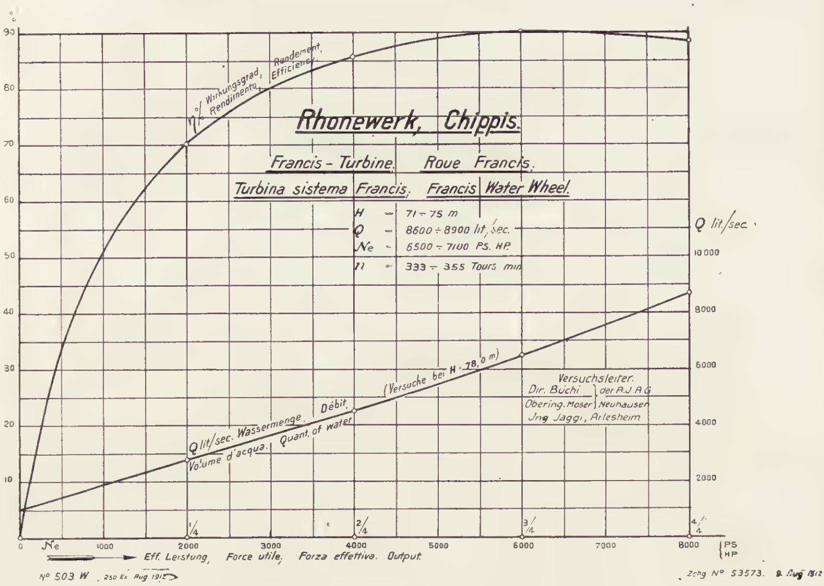


Fig. 7. Performance Curves of a Medium-Head Turbine

by rail, which necessitates large runners being made in several parts. All these requirements have already been complied with in quite a satisfactory manner; the runners of the Keokuk plant were made in different pieces, without any trouble resulting up to date. At the present stage of water turbine design, it is possible to deal with the enormous outputs mentioned above with single-runner turbines. Fig. 7 gives an idea of the efficiencies attained by a turbine of first-class design.

HIGH-HEAD TURBINES.

For about twenty years the Girard turbine has not been considered the best for high heads, as the type of both the guide apparatus and the runner of the Pelton wheel is, in principle, better adapted for high heads. The constant improvements to wheels of the Pelton type made in recent years have rendered these parts considerably more satisfactory than those formerly used. The increasing tendency to utilize higher heads made it necessary to overcome very serious difficulties in connection with the design of the Girard turbines, so that the Pelton wheel received much greater attention; and at the beginning of

this century, the latter type of turbine practically held the field in high-head water-power developments.

The first important high-pressure water-power plants were installed in Switzerland, and they were equipped with relief valves. The latter were, for the first time, to my knowledge, installed in a plant at Davos in Switzerland. These relief valves, which are designed for reducing as much as possible the overpressure arising in the penstocks after the sudden throwing off of load, have been very much improved since the first one was made. A large plant, which for many years was considered a standard installation of its kind and one of the earliest working under the high head of 400 metres, was installed at Brusio in Switzerland, in 1905. The twelve turbines installed have only one jet and develop 3500 hp. each, running at 375 r.p.m. The relief valves are designed as slide valves and are controlled by means of a dashpot. The Tyssedalen installation in Norway, running under a head of 380 metres, though also a large one, was laid down on similar lines. The turbines of the first installation develop 4600 hp. each, running at 375 revs. per minute. The Vermork station of the Rjukanfälle development in Norway, with a head of 250 metres, has already been equipped with large turbines developing 15,000 hp. with two runners, two jets working on each runner. All these turbines have horizontal shafts.

The vertical shaft arrangement of the Pelton wheel has also very marked advantages, especially where several jets are necessary to develop the intended output according to the head available. This new design was adopted for the plant at Necaxa in Mexico, which was equipped, in the first installation, with six generator turbines of 8200 hp. each, running under a head of 390 metres, started in 1905. Four years later, this power station was completed by the addition of two turbines of 16,500 hp. each, with vertical shafts, one runner and four jets. The water-power plant of Rio de Janeiro has been laid down on similar lines, the station containing six turbines of 9500 hp. each (see Fig. 8), and two additional ones of 19,000 hp. each (see Plates V and VI). All these turbines are of the vertical-shaft, single-runner, multiple-jet design. The thrust bearing has been installed, in all these turbines, on the intermediate

floor, below the generator. All have relief valves. The Necaxa plant has an additional relief valve, directly controlled by the pressure in the pipe lines, which is intended to reduce the over-pressure consequent on the sudden taking on of load by the turbine. An important Swiss plant is that of the Bodio installation of the Biaschina power development on the river Tessin, on the Southern slopes of the Alps. It has three generating turbines of 11,000 hp. each, running under a head of 255 me-

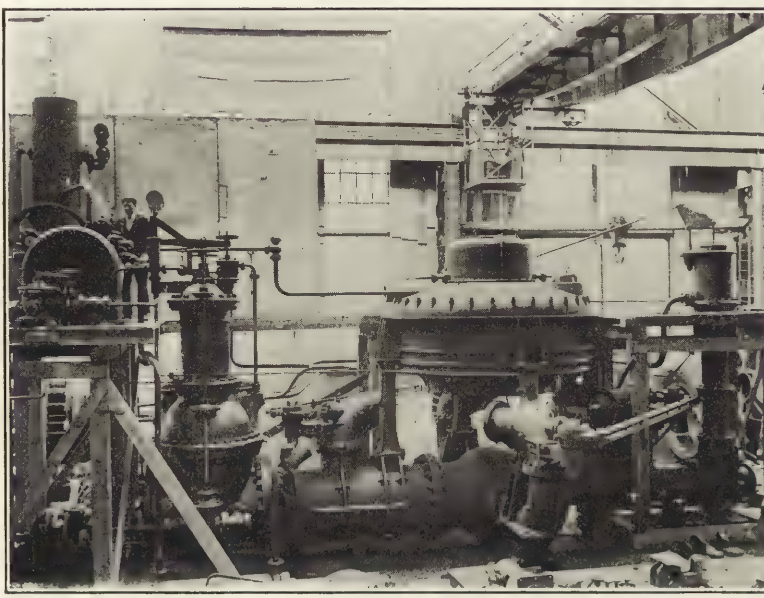


Fig. 8. Four-Nozzle Vertical Pelton Wheel, Rio de Janeiro T. L. & P. Co., Brazil.

$H = 270$ m.; $N = 9000$ hp.; $n = 300$

tres, with 300 revs. per minute. The length of the shaft is reduced as much as possible, and the thrust bearing is installed on the top of the generator, the exciter being mounted on the shaft end overhanging the thrust bearing. This arrangement is a very successful one, as it was possible, thereby, to keep the cost of the masonry part very low.

The relief valves are no longer satisfactory for heads of, say, 500 metres and upwards, as the high pressure practically entails the use of double the number of parts exposed to severe

wear, as, for instance, a turbine with a single jet has two outlets exposed to the full velocity of the water. The designers have attempted to arrive at a satisfactory arrangement with a single outlet for the water, acting as nozzle and relief valve at the same time, in order to avoid any dangerous pressure in the pipe line. This is possible by providing such a device as will divert from the runner the jet in the same instant that the load is taken off the turbine, thus preventing racing, and then slowly closing the nozzle, in order to reduce the flow of water to zero, for instance, when taking off full load. The closure of the outlet has, of course, to be made slowly, for the purpose of avoiding any dangerous increases of pressure. The first hydraulic engineer in Europe to apply this idea was Zodel, who designed the deflecting nozzle, which has been adopted for four turbines of the Adamello plant, working under a head of 950 metres. These turbines develop 6500 hp. each at 420 r.p.m. Much larger machines, of 14,000 hp. each, running under 520 metres head, at 370 r.p.m., have been installed at the power house of the Tata Hydro-Electric Works at Bombay, which have recently been started (see Fig. 9). Five turbines have been installed in the plant up to the present time, but it is intended to increase the number to eight. A very important plant, on the river Flamisell in Spain, has been laid down on similar lines to the Adamello installation; it contains four turbines of 8200 hp. each, running under a head of 830 metres (see Plate VII).

The governor, through a servomotor, acts directly on the needle of the nozzle, and by means of another servomotor which is controlled by a dashpot, it acts likewise to control the deflecting nozzle itself, the dashpot acting expressly for the return motion of the nozzle to its original position. Let us consider the position at full load. When suddenly taking off the full load, the dashpot of the second servomotor remains locked, so that the deflecting motion is effected in the shortest possible time, the jet being deflected without being changed. The position of the needle itself—that is, of the gear which operates it—is immediately changed in accordance with the new load of the turbine. The second servomotor is, in the meanwhile, acting slowly, owing to the action of the dashpot, and gradually turns the whole deflecting mechanism into its

original position. The time required for this combined movement varies in each installation according to the special conditions of the penstocks, in order that the resulting over pressure be hardly perceptible. When taking off the load slowly, the needle alone will be moved, on account of the fact that the dashpot does not influence the second servomotor. The latter, likewise, remains inert when load is put on, as the needle alone is moved.

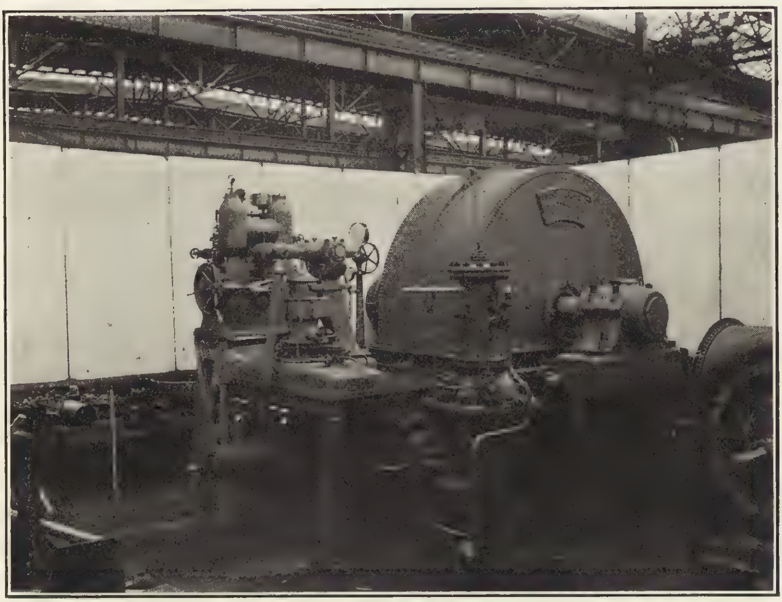


Fig. 9. Single-Nozzle Pelton Turbine (Deflecting Nozzle); Tata Hydro-Electric Power Plants, Bombay, India.

$H = 510$ m.; $N = 13,500$ hp.; $n = 300$

The improvements in developing this idea have led to the introduction of a new element, the deflector, which is placed between the outlet of the nozzle and the wheel itself and deflects the jet from the wheel as soon as the load is suddenly taken off. The nozzle is fixed, and this device has the advantage of being suitable for turbines with more than one nozzle. A very interesting application of this improvement has been made in the Arlia Power Station in Italy, where three tur-

bines of 2200 h. p. each, with two nozzles, were installed in 1912. The second installation of the Adamello plant was also made with turbines of this new design, each developing 8800 hp. The design, for standard machines of medium size, has been adopted in the Moncenisio Power Station, where two turbines of 2500 hp. each, running at 500 r.p.m., have been installed with this deflecting device. The tendency of modern designers is to increase the specific speed of Pelton wheels as much as possible, especially for heads of 300 to 500 metres, with the result that a

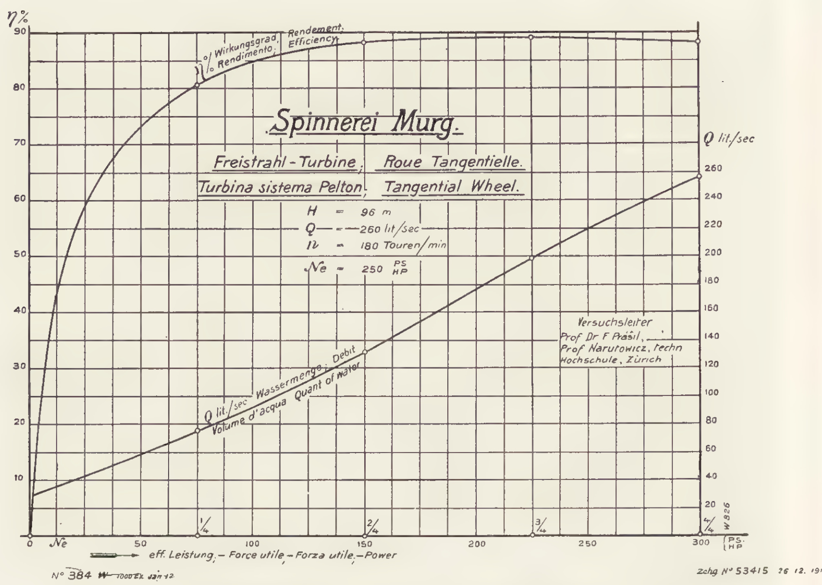


Fig. 10. Performance Curves of a Pelton or Impulse Water Wheel.

less expensive generator and electrical equipment is needed. The ratio of the diameter of the jet to the diameter of the wheel is increased as much as good efficiency will permit, especially to avoid, wherever possible, turbines with more than one nozzle. The large turbines, of 8250 hp. of the Borgne installation, running under 340 metres head and 300 revs. per minute with only one nozzle, have the largest jet (210 mm.) that has been made, up to the present. See Plate VIII. This design of Pelton water wheel, which is the newest and simplest, combines the greatest advantages with the lowest operating costs, the spare

and different parts exposed to wear being reduced to a minimum. The increase in the diameter of the jet naturally calls for an increase in the dimensions of the buckets, and the designer has had to solve very serious difficulties in order to arrive at a satisfactory method of fixing the buckets to the discs, taking into consideration the very strong centrifugal force and severe shocks, caused by the water jets, to which the buckets are exposed. In this connection, it is important to arrange the buckets in a complete rigid ring around the disc, this being done by means of various different devices. I may say that this difficulty is now absolutely removed. Pelton wheel units of the enormous output of 25,000 hp. each are already under consideration. A glance at Fig. 10 will show the range of efficiency of good Pelton wheels.

AUTOMATIC SPEED GOVERNORS.

About twenty or twenty-five years ago, the governing of the turbine, that is to say, the maintaining of a constant speed for every load, was accomplished by means of a mechanical governor intended to relieve the engineer of the trouble of attending to this point. The servomotor of the governor has to make an initial effort controlled by a pendulum, which is affected by every small and hardly perceptible difference of the speed. The designer used the water pressure available at the turbine itself for operating the servomotor in all the instances where it was possible and where the dimensions of the servomotor would allow it. The turbines installed for working under medium heads were first equipped with governors provided with automatic servomotors. For instance, the large turbines of 3200 hp. installed at the Kanderwerke in Spiez (Switzerland), working under a head of 62 metres and started in 1908, were equipped with water-driven servomotors. It is obvious that only the purest water can be used for such a purpose, in order to avoid any undue wear of the governing valves and so on, and it was therefore necessary to provide for very reliable working filters, or to use, as in some of the plants, water from other sources. Of course, the standard practice has been to filter the water of the turbine itself. Notwithstanding these precautions, the wear on all the regulating valves in such hy-

draulic governors was very great. The eddies in the servomotor, which could hardly be avoided, even in the best designs, also caused wear on the cylinders, bushings, stuffing boxes, etc., so that it was decided to use another liquid substance for the purpose, the more so as all the low-head plants could not yield pressure water themselves. The necessary water under pressure ought to have been supplied by separately installed pumps. As soon as pumps were found to be unavoidable, it was obvious that oil was preferable to water, on account of the numerous advantages which it offered. The first low-head water-power developments in Switzerland, at Rheinfelden and Chèvres, had already been equipped with oil pressure governors. The elements for these governors are, of course, the same as for the hydraulically operated ones, but I need hardly deal with them in detail.

The necessity of equipping each turbine, without exception, and irrespective of the head, with automatically operated governors has induced the designer to determine certain standard sizes, in order to build them in series. It was, and is, very important to reduce to a minimum the cost of this additional apparatus, especially for the smaller plants. The pressure of the oil is produced by pumps, which are generally driven from the main turbine shaft. Some pumps are even connected with the pulley of the pendulum. The pumps of the larger governors are generally driven by small water turbines. The servomotors are either symmetrical or differential, the former being chosen for the smaller governors, and the latter for the larger ones. The smaller governors are generally equipped with pumps sufficiently large to supply three or four times the necessary quantity of oil required for one complete movement of the servomotor. This condition is of practical importance for all governors, for the pumps would be too large and too expensive for that purpose should they have to deal with such large quantities of oil for larger governors. The well known principle of differential pistons was developed in all piston pumps of about twelve or fifteen years ago, and has generally been adopted for the larger governors, as two advantages are obtained at the same time. The pump needs only a capacity of one third to a quarter of the total volume of the oil required (the remainder

being kept in a reservoir with an air vessel) according to the design of the piston pump. The smaller end of the differential piston is constantly under pressure, which prevents the turbine being started before the governing valves have acted.

The improvement recently made in the working of the smaller oil pressure governors is that of allowing a certain clearance on the governing piston, instead of an overlap, so that in connection with the symmetrical servomotors the pressure of the pump is reduced almost to zero all the time the load is constant on the turbine, and the full working pressure is supplied by the pump only when the guide vanes of the turbine are to be moved. The great advantage of this design is the greatly reduced heating of the oil during the operation.

The present tendency in the design of the oil pressure governors is to reduce as much as possible the so-called closing time of the governors, that is, the time necessary to shut down from full- to no-load the guide vanes of the turbine. The flywheel momentum of the turbine, to insure very small variations of the velocity when taking off the load, is reduced in a rate proportional to the closing time. The controlling gears of the governor are made as sensitive as possible, and very interesting improvements are constantly being embodied. The standard relay mechanism of the governor provides for a variation of 3 to 4% of the speed between no-load and full-load, the speed at no-load being higher. In practically all the governors of good design, it is possible to change the range while the governor is running, and it is even possible to reduce this variation to zero. This is the so-called isochronous regulation, which has already been tested when starting the large turbine plant at Niagara Falls. It is also possible to have a negative range of velocities, the speed increasing with the load. The most important tendency is the increasing of the sensitiveness of the pendulum and the smaller controlling gear of the governor. The reduction of the mass to be moved by the pendulum is, especially, the most striking feature of the newest designs. On the other hand, the manufacturers are trying to reduce as much as possible the number of pieces which cannot be made in series, and this effort seems to be finding favour more and more.

The modern oil pressure governor is an extremely ingenious mechanism, requiring the highest class of workmanship, and is the essential factor which renders the installation of larger and larger power stations possible, under the control of very reduced staffs.

CONCLUSION.

In concluding this short paper, I do not hesitate to say that the modern design of each of the three kinds of water turbines, for low-, medium- and high-head water developments, has solved all the important problems connected with the installation of plants for very large outputs, at speeds as high as possible and with the most accurate governing devices. This remarkable result is due to the perfect co-operation of applied sciences, the constant improvement of manufacturing methods, and the high grade of workmanship obtained in shops with up to date equipments. The near future will show still more rapid developments than the last fifteen or twenty years, on account of the splendid conditions under which improvements can be effected nowadays. Indeed, any new demand for water power developments under the most difficult conditions can now, without hesitation, be met and be certain of success from the very beginning.

DISCUSSION

Mr. Doble.

Mr. W. A. Doble,* M. Am. Soc. C. E., said that Mr. Zoelly in his paper must surely refer to European practice when speaking of the use of deflecting nozzles, because they were used in this country long before they were introduced into Switzerland.

In reference to relief nozzles not being used under heads higher than 500 meters, they were to be found in this country under much higher heads.

It must be borne in mind, when reading Mr. Zoelly's paper, that all water wheels in Europe are called ''turbines''. The turbine of the vertical form for medium and high heads was developed in the United States, where metallic construction carries the stationary and revolving elements. The first installation of this type was at Schaghicoke, N. Y.

* Chief Engr., Pelton Water Wheel Co., San Francisco, Calif.

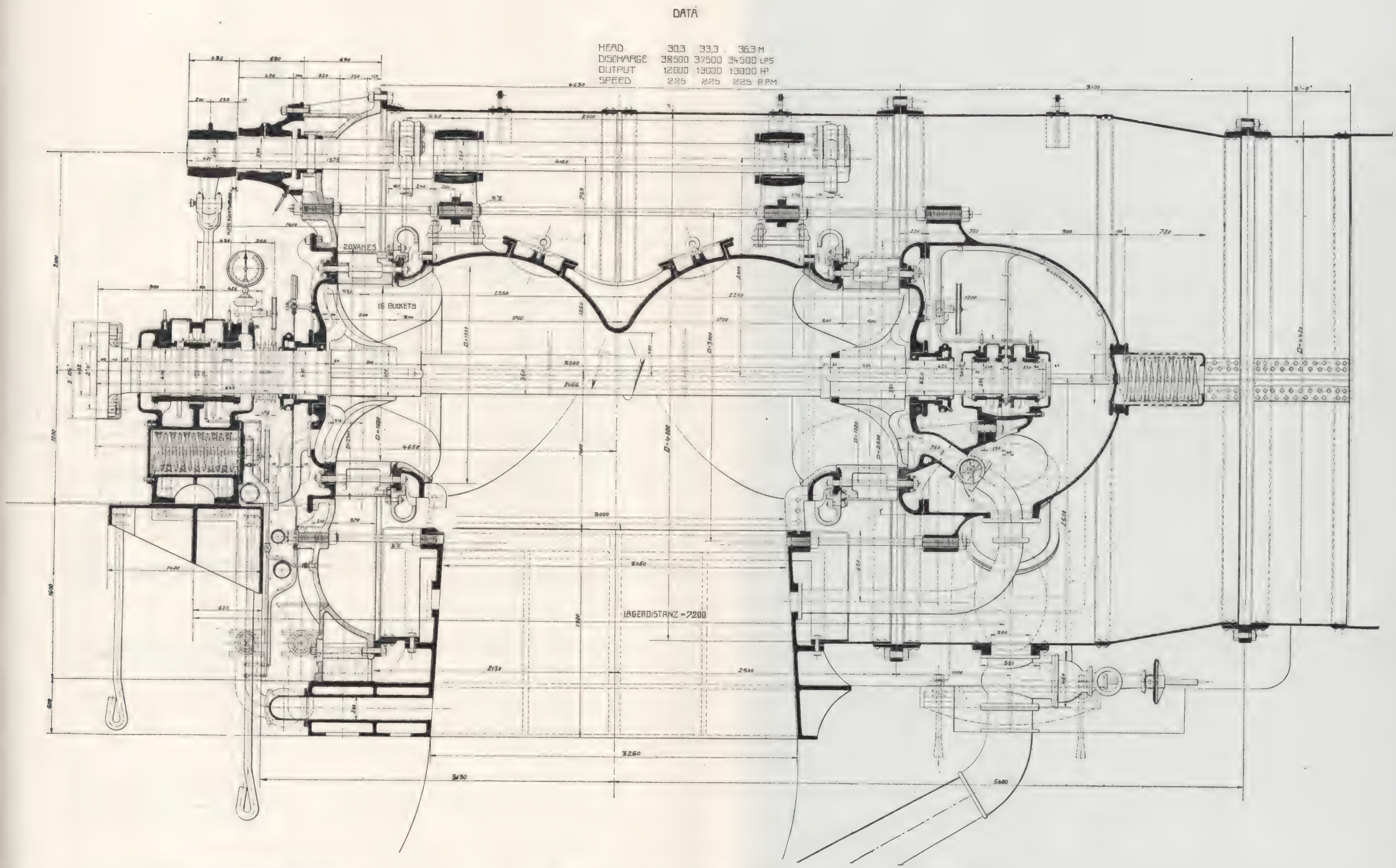


Plate I. Twin-Runner, Horizontal-Shaft Turbines with Control Mechanism inside of Cylindrical Casing; Stave Lake Power Plant, Vancouver, B. C.

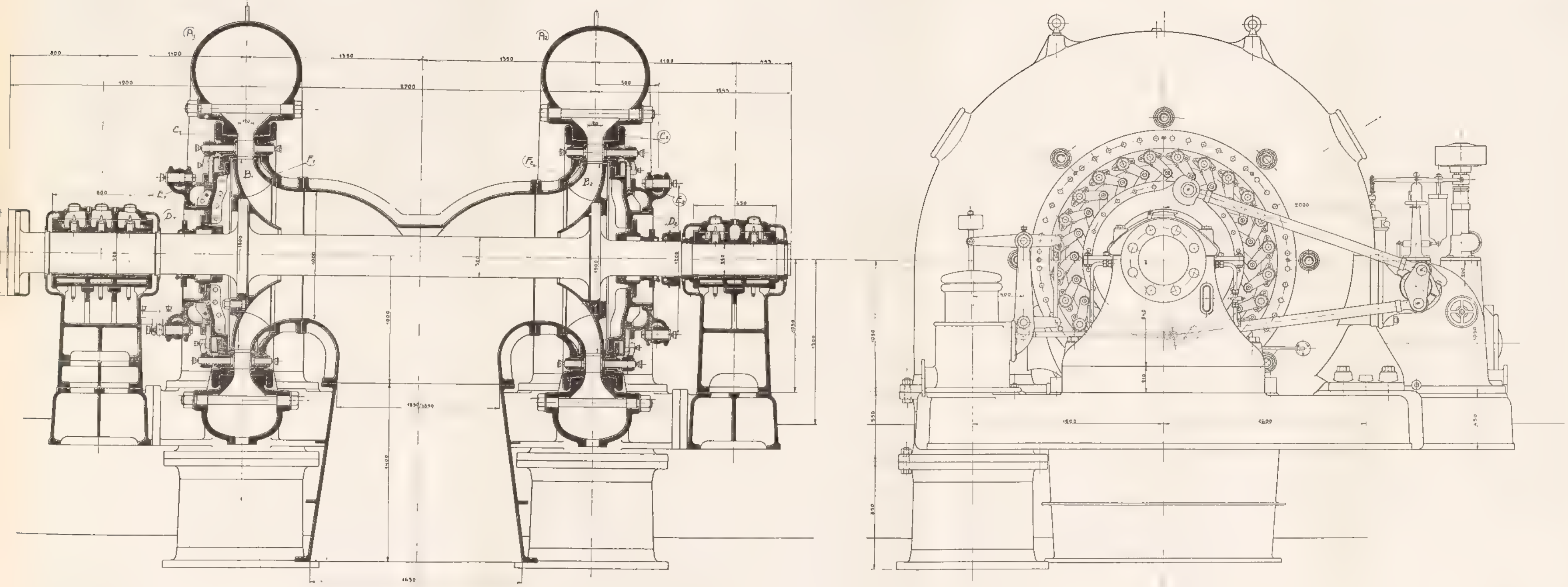


Plate II. Twin-Runner, Horizontal-Shaft Turbine with Spiral Scroll Cases and External Control; Tokyo Electric Light Co., Tokyo, Japan.

Data

Head	— 112 120 5 Meters
Discharge	— 9,700 10,600 Liters per Sec.
Output	— 12,500 H P
Speed	375 R P M

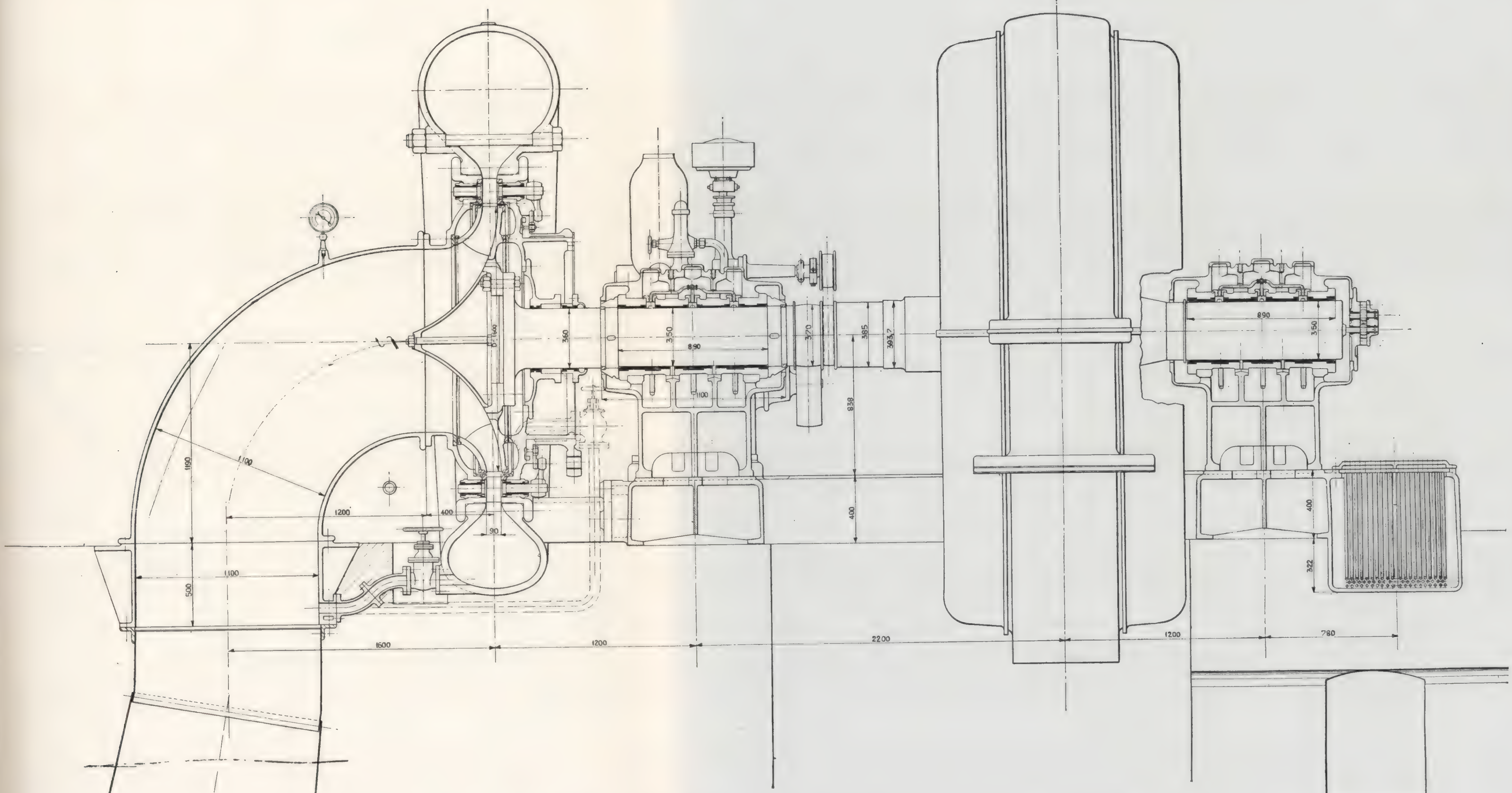


Plate III. Single-Runner, Horizontal-Shaft Turbine with Spiral Scroll Case and External Control. Head 170 m. (558 ft.); Tuxpango, Mexico.

Data

Head	= 166 Meters
Discharge	= 4800 Liters per sec.
Output	= 8500 H.P.
Speed	= 400 R. P. M.

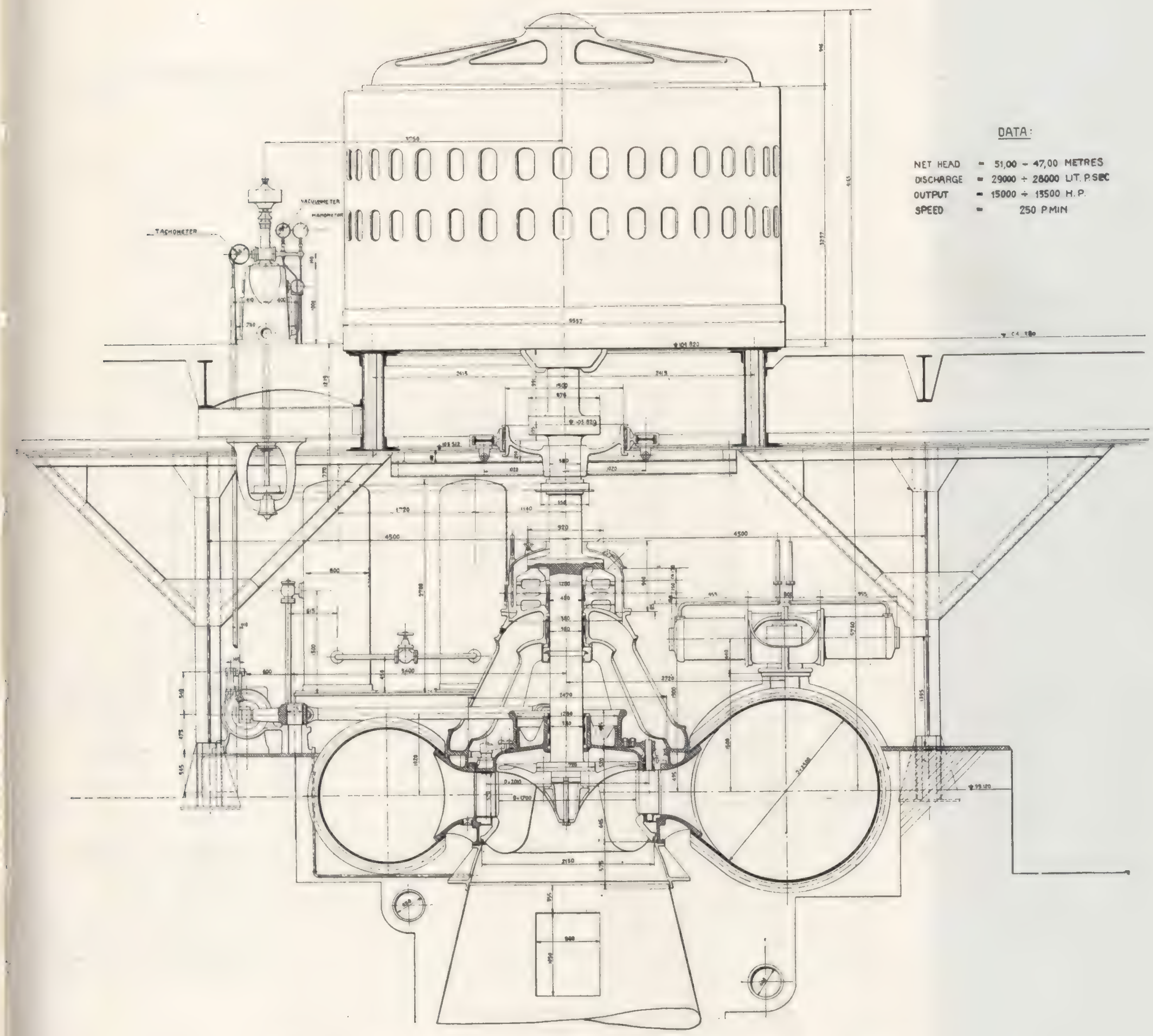


Plate IV. Single-Runner, Vertical-Shaft Turbine with Spiral Scroll Case and External Control; Seros Plant, Ebro Irrigation & Power Co., Ltd., Spain.

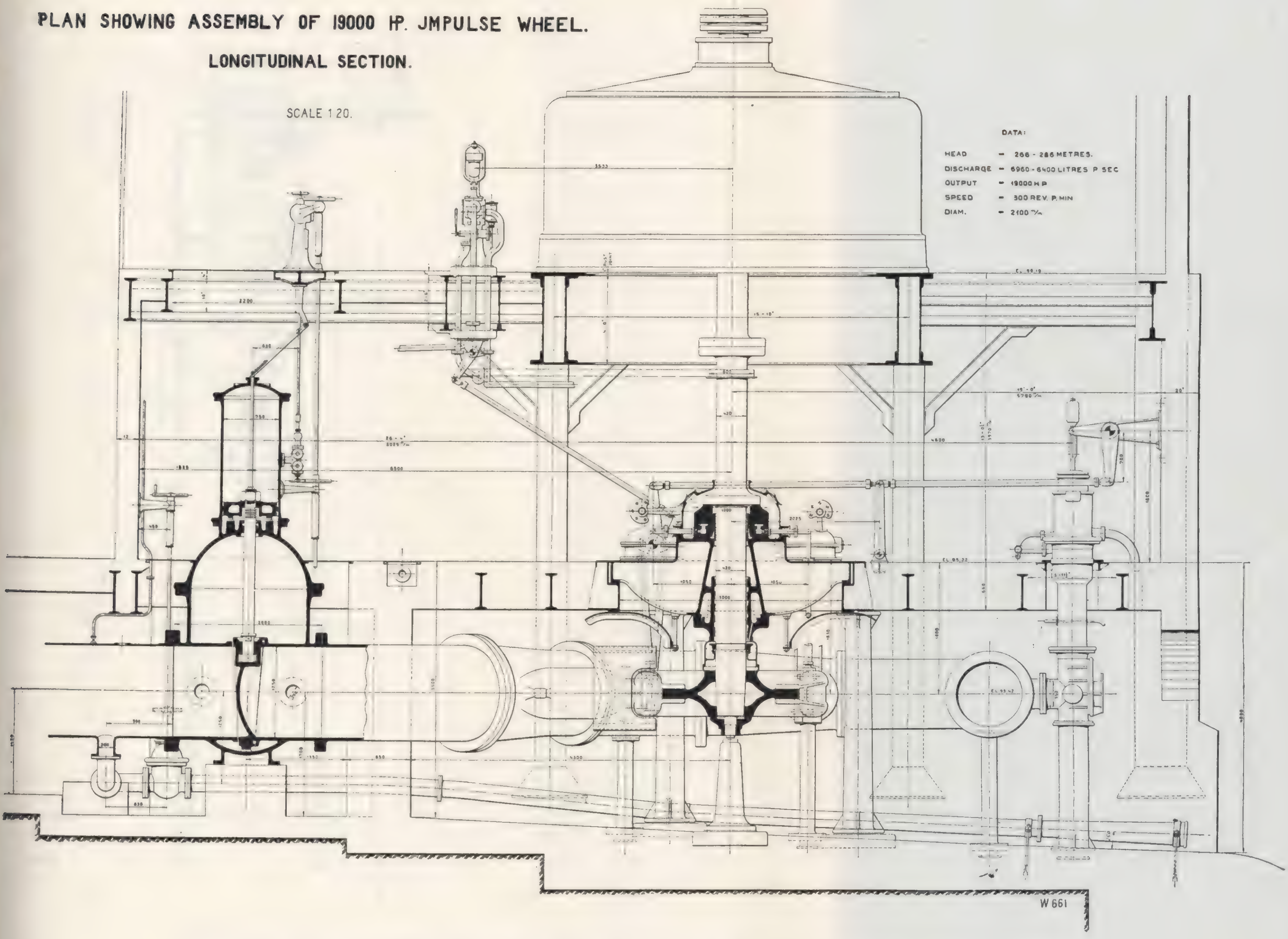


Plate V. Single-Runner, Four-Nozzle, Vertical-Shaft Pelton Wheel; Rio de Janeiro Tramway, Light & Power Co., Brazil.

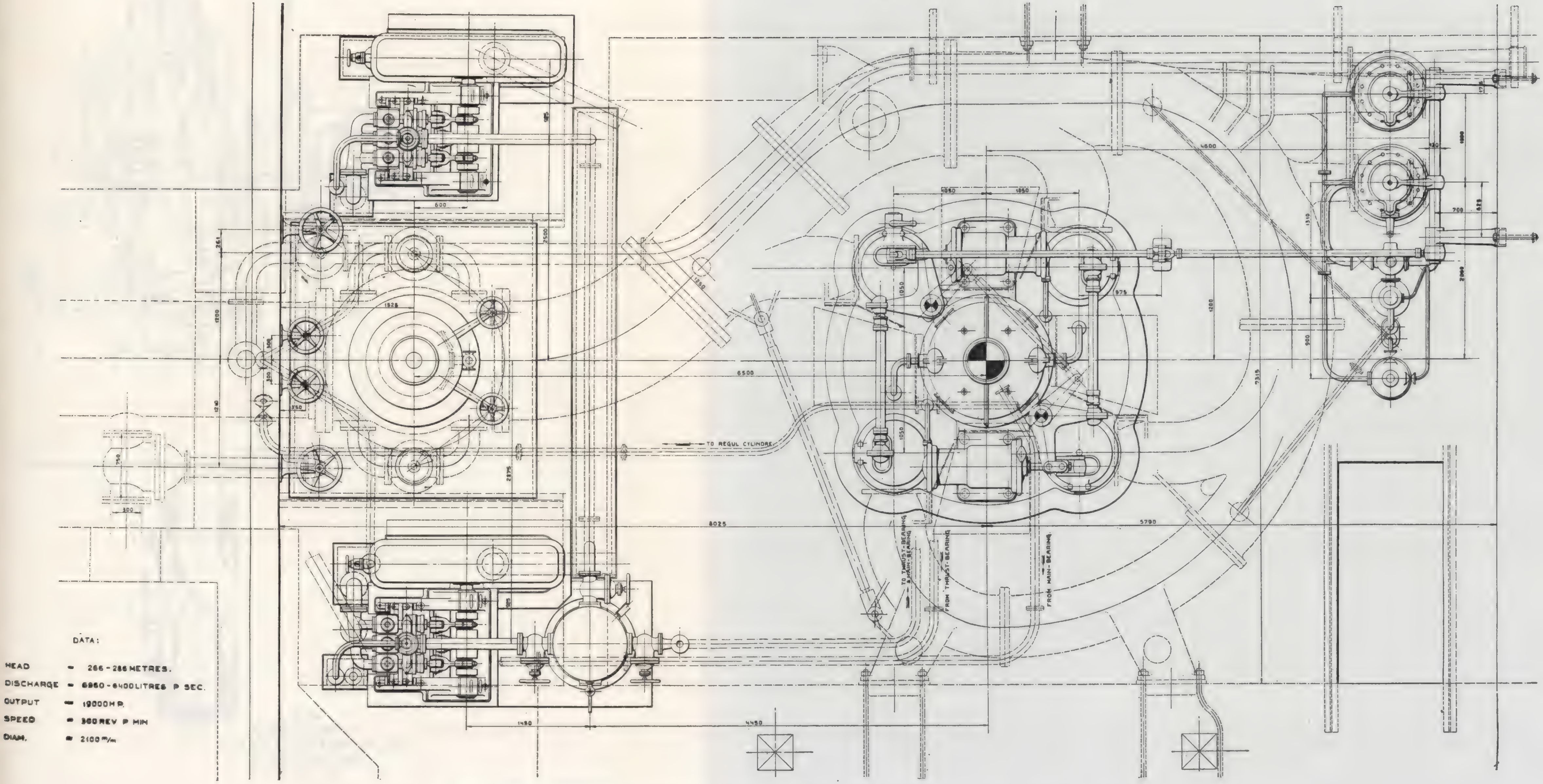
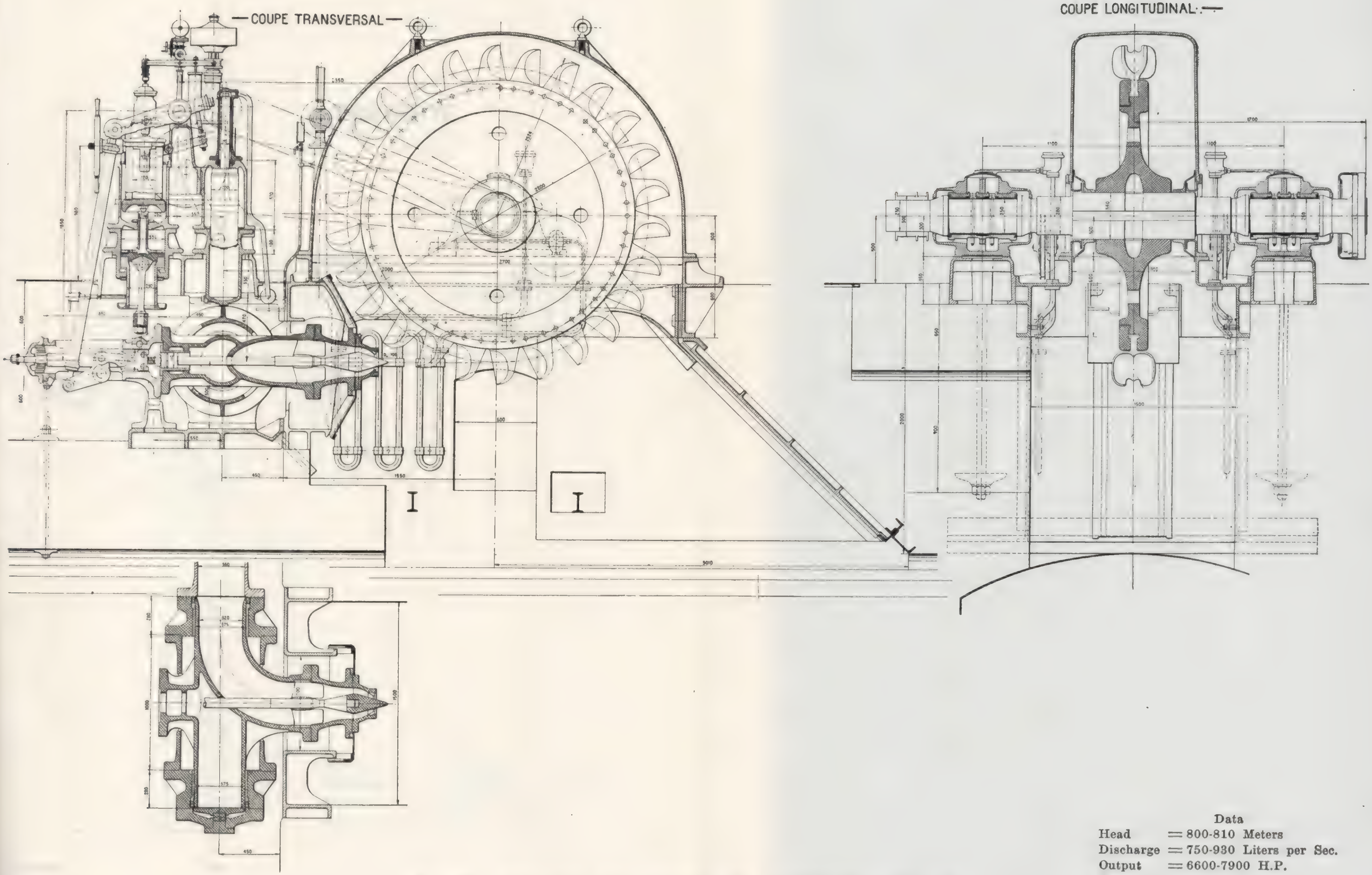


Plate VI. Single-Runner, Four-Nozzle Vertical-Shaft Pelton Wheel; Rio de Janeiro Tramway, Light & Power Co., Brazil.



Data	
Head	= 800-810 Meters
Discharge	= 750-930 Liters per Sec.
Output	= 6600-7900 H.P.
Speed	= 500 R. P. M.

Plate VII. Single-Runner, Single Deflecting Nozzle, Horizontal-Shaft Pelton Wheel under a Head of 830 m. (2722 ft.), on the Flanaisell River, Spain. S. A. Evergia Electrica de Cataluña, Barcelona, Spain.

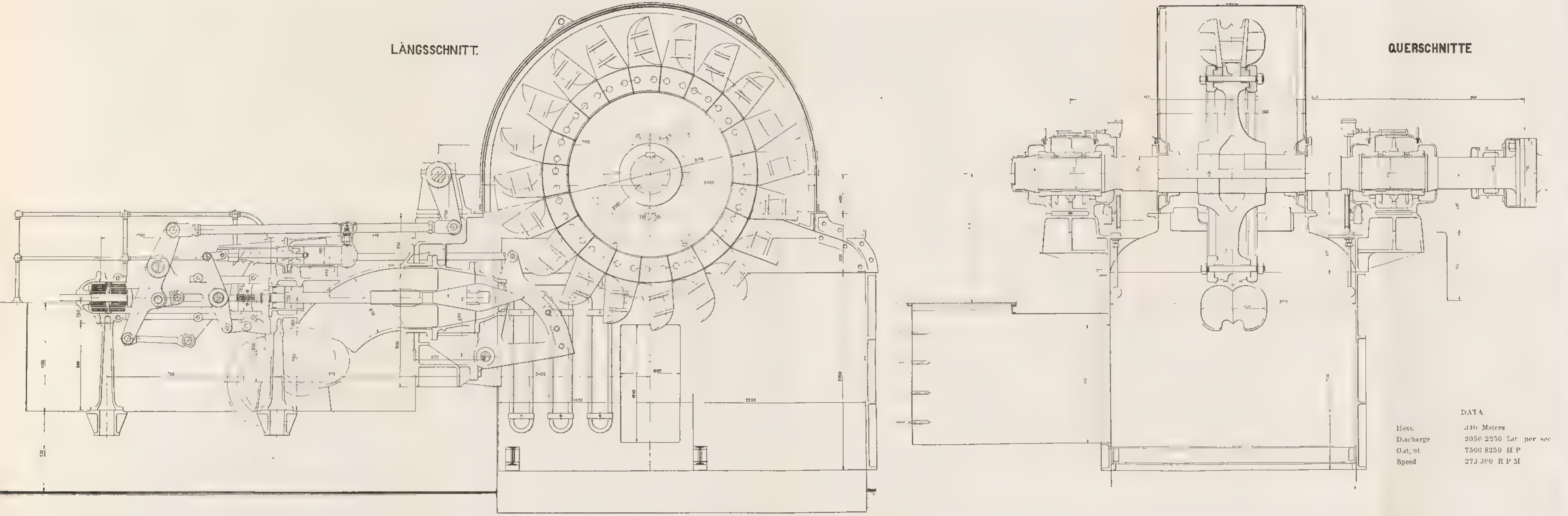


Plate VIII. Assembly Plan of the Borgne Installation of the Aluminium Industry Co.

Paper No. 148

WHEELS OF THE PRESSURE TYPE.

By

ARNOLD PFAU, Mem. Am. Soc. M. E.
Milwaukee, Wis., U. S. A.

PREFACE.

The limited space of this paper and the wide range of design and practical application covered by wheels of the pressure type do not permit of much more than a condensed treatment of the subject. This may be accomplished in a fairly digestible manner by selecting eight chapters in which the various points are dwelt upon.

Chapter 1. Theoretical Definition.
" 2. Previous Art and Present Art.
" 3. Applicability.
" 4. Classes, Types and Characteristics.
" 5. Description and Selection of Type.
" 6. Efficiencies and Tests.
" 7. Accessories.
" 8. Some General Remarks and Suggestions.

Throughout the paper, a knowledge of the basic principles of water wheels must be presumed in order to keep the paper within the permissible space. In a separate list, are given all references to the bibliography of the subject.

THEORETICAL DEFINITION OF WHEELS OF THE PRESSURE TYPE.

From a purely theoretical point of view, we may distinguish two, or possibly three, types of wheels (turbines), the classification arising from the method adopted in transmitting the energy of the moving water to the wheel. This will be apparent from the following discussion:

In Fig. 1—Let H be the effective head in linear units.
" H_n be the head after all friction losses up to the speed gate are deducted.
" H_s be the pressure head which may exist between speed gate and runner of the turbine.
" C be the spouting velocity of the water under head H.
" C_n be the spouting velocity of the water under head H_n.
" C_s be the velocity resulting from the head H_s in the turbine.
" g be gravity = 32.2 feet, or 9.81 meters per second at sea level.
" V be the absolute velocity of the water issuing between the guide vanes.

The head H_n is either partly or wholly transformed into velocity between the guide vanes or the speed gate.

$$C_n^2 = V^2 + C_s^2$$
$$C_s = \sqrt{C_n^2 - V^2}$$

The velocity C_s represents a velocity due to a head $H_s = \dfrac{C_s^2}{2g}$ which head, expressed as a pressure, $p_s = \dfrac{C_s^2}{2g}\rho$, is commonly termed the reaction pressure. In this expression, ρ is a factor expressing the relation between pressure expressed as head measured in linear units and the same expressed as a given force per unit of area.

In this relation of $C_s = \sqrt{C_n^2 - V^2}$ we may distinguish three specific cases:

(1) $C_s = O$ $V = C_n$ atmospheric conditions
(2) $C_s > O$ $V < C_n$
(3) $C_s < O$ $V > C_n$

(1) $C_s = O$. The entire net head H_n is transformed into velocity. Wheels of the above characteristics are termed action turbines, or wheels of the impulse type. (Girard turbines, or axial discharge action turbines with ventilated runner chutes.) In turbines of this type, the air may be admitted through vent-holes in the side walls of the runner, below the rear entrance portion of the runner vanes, or it may be directly admitted through the space between speed gate and runner. An example of the outward discharging action turbine is the Schwamm-Krug turbine, which is practically the same as the Girard turbine except that the water does not flow parallel with but at right angles to the shaft.

Instead of ventilating the runner chutes to enable the jets to cut loose from the rear of the preceding runner vanes, the rear

FIG. 1.

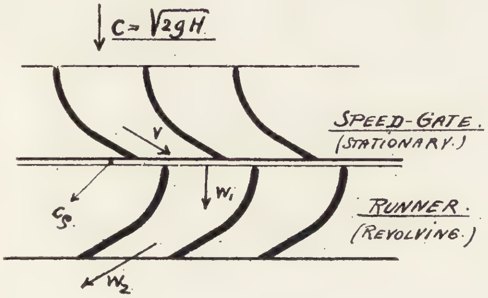


FIG. 2

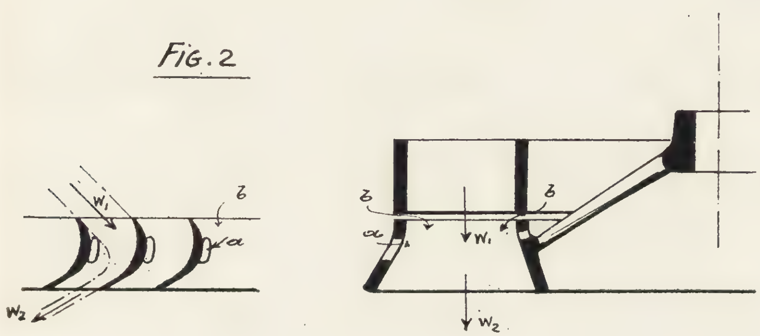
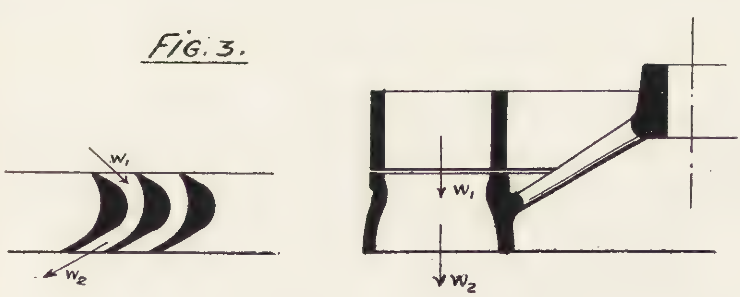


FIG. 3.



of the vanes may be so shaped that they reduce the area of the chutes to that required by the jets as is shown in Fig. 3. Thus a ventilation becomes unnecessary. Wheels of this design are called

Limit- (Grenz) turbines, and may have axial as well as radial outward or even radial inward discharge.

The above types are representatives of the older art and are hardly considered in modern practice.

The only example of this type of wheels entitled to consideration at present is the Impulse wheel which is better known as the Pelton Wheel, in due honor of L. A. Pelton, the inventor.

It is a combination of a right hand and a left hand axial-discharge Girard-turbine, with the entrance portions of the runners symmetrically joined together and with the outer rims of the runners omitted, (Fig. 4) so that the water leaving the speed gate can enter along the radial central plane of the wheel.

(2) $C_s > O$. In this case part of the net head H_n is transformed into velocity, and part is retained in form of the so-called reaction pressure $p_s = \frac{C_s^2}{2g} \cdot \rho$

Wheels of the above characteristics are termed reaction turbines or wheels of the pressure type, and will be made the special subject of this paper.

(3) $C_s < O$. In this case not only is all the head H_n transformed into velocity, but an artificial suction is produced in the clearance between speed gate and runner, resulting in an acceleration of the velocity V to the extent that it exceeds the net velocity C_n. Wheels of this characteristic may be termed wheels of the "Under-Pressure" type. Such wheels have not as yet been introduced into actual practice but the design was fully brought to public attention by Prof. Dr. H. Baudisch, of Vienna, in his article published in the Zeitschrift für das gesamte Turbinenwesen, May 10 and 20, 1914.

The reaction or over-pressure velocity C_s (be it over-pressure as under 2, or under-pressure as under 3) is produced by the difference between relative inlet velocity W_1, and relative outlet velocity W_2, viz., $C_s^2 = W_2^2 - W_1^2$. For the sake of simplicity it can be assumed that the water flows on a cylinder with its axis coinciding with the axis of rotation of the runner, so that $R =$ a constant whereby no corrections have to be made due to changes of peripheral speeds. (Note additional velocity component C_F introduced by Professor Dr. H. Baudisch in his article referred to before.)

PREVIOUS ART AND PRESENT ART.

To distinguish wheels of the pressure type according to the position of the shaft, viz., horizontal, vertical or inclined, does not provide a proper classification. Let us, therefore, classify them according to the direction of flow of the water with reference to the shaft.

Thus we have wheels with:

1. Radial outward discharge, Fig. 5.
2. Diagonal outward discharge, Fig. 6.
3. Axial discharge, Fig. 7.
4. Diagonal inward discharge, Fig. 8.
5. Radial inward discharge, Fig. 9.
6. Combined radial or diagonal inward axial and diagonal or radial outward discharge. Fig. 10 a-c-e-f.

Radial Outward Discharge.

This is the oldest type of turbine. It was invented by the French engineer, Fourneyron, in 1827, who rapidly brought his design to a fair degree of perfection, both as a reaction wheel as well as an action wheel. That the splendid qualities of this wheel were highly appreciated may be shown by the fact that this type was proposed for the first installation at Niagara Falls by the reputable Swiss concern, Piccard Pictet & Company of Geneva, for the first set of 5000 hp. turbines, and which was accepted by the board of the prominent engineers who were instrumental in the construction of this first large hydro-electric plant. It deserves to be noted in history that these wheels were kept in operation for 18 years until they were replaced by more modern equipment. The rapid advance of the art by developing more efficient wheels has reduced this type to one of historical interest only.

Axial Discharge.

This type was first built by Henschel and Son, Kassel, Germany, in 1837, and was successfully introduced into practice by the French engineer, Jonval, in 1841 when the first wheel was built at the machine shops of A. Koechlin of Mulhouse, Alsace. The advantages of this type over the radial outward discharge type were so apparent that it not only eliminated the latter from the market almost entirely, but also maintained its supremacy for the rest of the century, particularly in Europe and in the

countries to which Europe exports. This type, too, has been eliminated and has become of historical interest only, except in a few cases, where it is built by less progressive manufacturers.

Radial Inward Discharge.

This type was invented by the American engineer, J. B. Francis, as early as 1849. The fact deserves attention that in

FIG. 4.

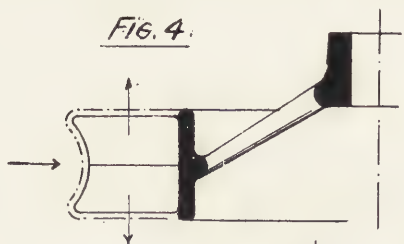


FIG. 5.

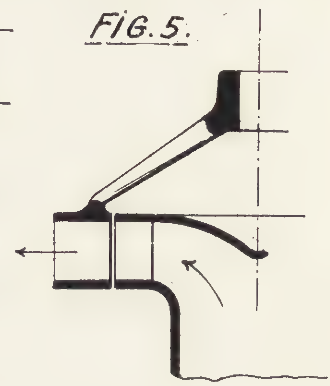


FIG. 6.

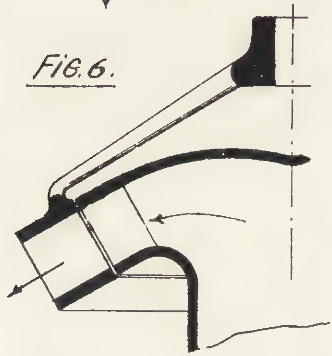


FIG. 7.

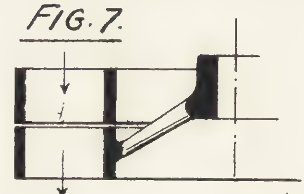


FIG. 8.

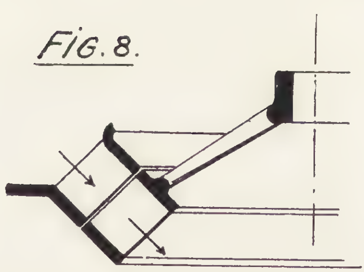
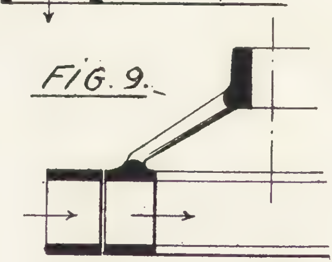


FIG. 9.



spite of its eminent qualities this type of wheel did not force its way into European practice until the last decade of the past century. An explanation of this may be offered. Francis's invention was at once picked up by American manufacturers and was rapidly developed by their engineers, or sub-inventors as

we may call them, being introduced into the American market under pompous trade names such as Hercules, Victor, Giant, etc. These various makes of wheels were manufactured in lots from standard patterns and being nothing more than stock-trade-articles the invention failed to impress the engineering world

FIG. 10 a.

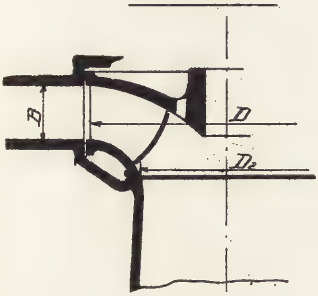


FIG. 10 d.

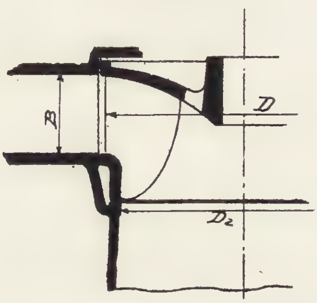


FIG. 10 e.

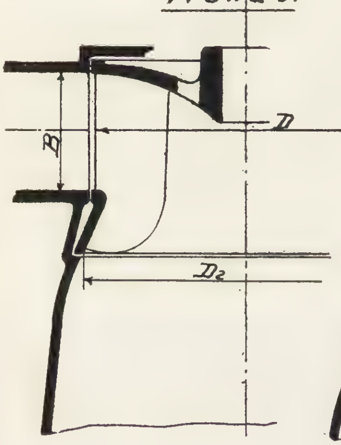
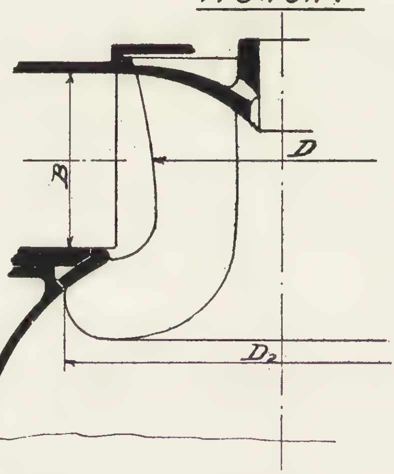


FIG. 10 f.



as to its real value. Thus the merit of the Francis wheel was restricted to such reputation as may be obtained by any manufacturing product advertised as a standard article in trade catalogues. It was not until European manufacturers began to develop this type of wheel that it became known again under

the proper name of its inventor, and it was not until some twelve years ago that the name Francis turbine became more popular in the United States, thanks to a large manufacturing concern whose engineers persistently used this term in due honor of its inventor, who was an American. It was the dawn of a new era in which the stock wheels began to yield their ground to Francis turbines designed and built to meet exactly the conditions under which they were to operate, and it is significant that today's advertisements are practically free of any reference to trade names. With the rapid development of the Francis turbine, radical departures were made from the strictly radial inward flow, so that the Francis turbine of today belongs to the sixth class cited, namely that of the combined radial-inward, diagonal-inward, axial, diagonal-outward and possibly even radial-outward discharge wheels.

Diagonal Outward Discharge.

This type was introduced soon after the Jonval turbine entered the field. It did not, however, offer sufficient advantages over the other existing types, and therefore failed to obtain more than a historical value.

Diagonal Inward Discharge.

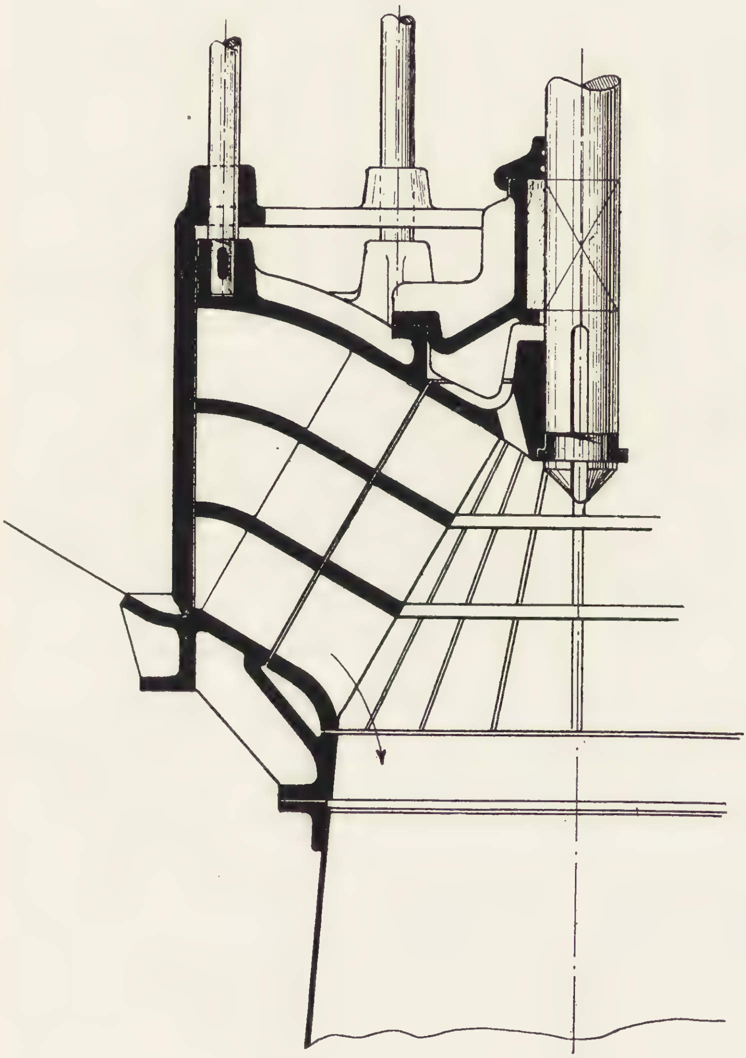
This type was introduced into practice by Escher-Wyss & Company of Zurich, Switzerland, in the early nineties, and was frequently and successfully used with large units, of which we may mention that at Chèvres, near Geneva, Switzerland, at that time a very large hydro-electric plant. Due to the fact that this design was protected by patents controlled by one concern its use in practice was naturally limited. We may consider this type a modest forerunner of the Francis turbine of today, as may be evident from Fig. 11 which is a sketch of a 2200-hp. runner designed by the writer in 1897 while in the employ of Escher-Wyss & Company. It can be seen that the lowest portion of the diagonal (or Conus) runner resembles the Francis runner of today for moderate capacity. This type has also withdrawn into the annals of history.

A review of the above chapter reveals the fact that the present art has done away with the various types cited, and restricts itself to the exclusive use of the Francis turbine as the only wheel of the reaction or over-pressure type.

APPLICABILITY.

The Francis turbine of today has displaced all other types of reaction-turbines or wheels of the over-pressure type. Similarly it can be stated that the bucket type of impulse-wheel or

FIG. 11.



Pelton type has taken the field against all other action or impulse (pressure-less) wheels. The fact that the entire range of head available for the development of water power can be covered by only two types of wheels has naturally broadened the scope of application of these two types.

Let us briefly compare the principal characteristics of these two types without invading too far the territory of the topic, "Water Wheels of Impulse Type".

(a) With a reaction turbine the fundamental requirement is that the water enter the runner over its full peripheral entrance area.

(b) With an impulse wheel of the bucket type, it is essential that the jets entering the buckets be kept sufficiently apart to avoid interference with a free, undisturbed discharge from the buckets. This means two things:

1. That only part of the periphery of the runner receives operating water.

2. That the space surrounding the buckets, at least at the place where the water discharges from same, must be liberal, in order to avoid losses.

The fulfillment of these two requirements would have a very negative effect with a Francis turbine, where it is essential that the jets entering the runner be never separated and where the water discharging from the runner be kept together in a solid column of uniform flow.

The Francis turbine is, therefore, adapted to discharge much larger quantities of water per diameter of runner than is the case with the impulse wheel. Its field of application, therefore, begins with the lowest heads which can be commercially developed and ends with heads which reach well into the field of the application of impulse wheels. The limit cannot be given in abstract figures, because it varies with the power and speed required. For instance, small power at high heads requires a small quantity of water discharged, resulting in small width of the runner, in which case the skin friction may become so considerable that the efficiency of a Francis turbine would fall below that of an impulse wheel. Similarly a low speed for a high head requires a large diameter of runner resulting in the

same disadvantages for a Francis turbine. The converse of these statements is true of an impulse wheel. The lower the head the larger the area of the jet or the greater the number of jets; the higher the speed, the smaller the impulse diameter of the bucket runner. Both invite danger in regard to possible interference resulting in low efficiency.

The remarkable advance made in the development of water power for electrical transmission, the existence of large power concerns with power systems into which numerous hydro-electric, steam- or gas-prime-mover plants are tied in, has justified the increasing demand for hydro-electric units of capacities hitherto unheard of. This tends to broaden the field of application of the Francis turbine in both directions of head, particularly, however, in regard to high heads, and today it is perfectly possible to find progressive manufacturers, who will offer Francis turbines of large capacities for heads as high as 300 metres (about 1000 ft.) provided that the operating water is free of silt or mineral acids.

CLASSES AND TYPES.

Various classifications of the great number of types of Francis turbines may be made, depending entirely on the respective points in view.

We may classify according to:

a. The characteristics of the runner; low, medium and high speed.

b. The position of the shaft; vertical, inclined, horizontal.

c. The setting; open flume and encased.

d. The number of runners employed; single, double, triplex, quadruplex, etc., for direct connection to generator or energy absorber or the geared type, where a plurality of single vertical units are bevel-gear-connected to a common line shaft.

e. The method of controlling the flow; cylinder gate, wicket type, or swivel gate.

(a) Classification According to the Characteristics of the Runner.

The wide range of head covered by the various types of modern Francis turbines, and the requirements of speed of the

electrical or other machines which are driven by them have brought about an elaborate classification of the Francis turbine runners. With low head developments, the speed must be selected as high as is good engineering practice in order to keep down the weight and consequently the costs of the generators. With very high heads it is mostly a question of keeping the speed reasonably low so as to avoid the use of costly high speed generators. The limit of high speed for low head developments is fixed by the progress of the art of designing high speed runners. The limit of low speeds under high heads is fixed by the risks taken by the manufacturers in designing runners for operation with very low coefficient of peripheral speed.

High speed under low heads also means large discharge capacity per unit diameter, resulting also in large power capacity. The problem to be solved is to design a runner which has a high peripheral speed coefficient μ in the formula:

$$\mu = \frac{D_1 \pi N}{60 \sqrt{2 g H}}$$

where

N = Revolutions per minute
D_1 = Mean inlet diameter
H = Net effective head

and which discharges a maximum quantity "Q" at the given area of runner in the formula:

$$Q = \frac{D_a^2 \pi}{4} V_3^{\times} \sqrt{2 g H}$$

where

$V_3 = V_3^{\times} \sqrt{2 g H}$
D_a = Maximum outlet diameter.
V_3 = Average absolute velocity at area where diameter = D_a.

This invites a large outlet diameter and a high average velocity V_3 of discharging water. Since $\frac{MV_3^3}{2}$ represents the energy contained in the water discharging at the velocity V_3, it can be readily seen that unless this energy is utilized somewhere else it is lost to the turbine and so causes a reduction of the efficiency of same.

The input energy is $\frac{MC^2}{2}$, consequently the hydraulic efficiency $e = 1 - \left(\frac{V_3}{C}\right)^2$ up to the runner outlet, or total hydr. $e = 1 - (V_4^{\times})^2$ where $V_4^{\times}$ represents the coefficient of velocity $V_4 = V_4^{\times} \sqrt{2 g H}$ at the end of the draft tube.

Low speeds under high head mean a small discharge capacity per unit diameter resulting in a small width of the runner. The problem to be solved here is to design a runner which has a low peripheral speed coefficient, and which discharges a relatively small quantity of water at the given area of runner.

The peripheral speed U^{x} is a function of the reaction velocity C_s^{x}.

The well known fundamental equation for turbines is:

$$U_2^2 - U_1^2 = W_2^2 - W_1^2 - C_S^2$$

or $$\left\{\left(\frac{U_2}{U_1}\right)^2 - 1\right\} U_1^2 = W_2^2 - W_1^2 - C_S^2$$

where

U_2 = peripheral outlet diameter speed.

U_1 = peripheral inlet diameter speed.

For constant diameter $W_2^2 - W_1^2 = C_{sc}^2$.

thus $$\left\{\left(\frac{U_2}{U_1}\right)^2 - 1\right\} U_1^2 = \left\{\left(\frac{C_{sc}}{C_S}\right)^2 - 1\right\} C_S^2.$$

$\frac{U_2}{U_1}$ represents the ratio of the two peripheral speeds. $\frac{C_{sc}}{C_s}$ is the ratio of the constant diameter reaction velocity to the actual reaction velocity and the values $\frac{U_2}{U_1}$ and $\frac{C_{sc}}{C_s}$ are, therefore, of related character and we can write $U_1^2 \times a = C_s^2 \times b$ where "a" and "b" represent constant values for a fixed design. Thus it can be seen that for a decreasing value of U_1 the reaction velocity C_s must also decrease.

A low peripheral speed invites possible danger of reaching into the range of the action or pressureless turbine ($C_s = O_1$) or even of the under-pressure turbine ($C_s < O$).

A failure of a high speed, high capacity runner design to operate under low heads becomes evident by lack of power or proper speed; a failure of a low speed runner design operating under high heads does not become apparent by lack of power or speed, but more frequently shows by excessive wear and tear of the runner proper. The cause can be traced back to the improper selection of the angles in the design with the result that conditions arise within the turbine, as have been pointed out before.

Not infrequently it can be observed that high head Francis turbines when operating at small gate opening, produce a noise which under certain circumstances increases from the sound of

rifle fire to that of reports of a small cannon. By proper introduction of air this noise can be stopped entirely and the efficiency be improved, in spite of the fact that the vacuum of the draft tube is somewhat reduced by the air admitted. Such turbines are no longer operating as over-pressure types but as pressureless or even under-pressure types of defective design.

Prospective purchasers of high-head Francis turbines may, therefore, be cautioned against considering low bids from manufacturers who lack the experience along the lines of proper design.

Between the two limits of head and speed there is still a vast field for the application of Francis turbines.

The term specific speed (or better "characteristic speed") has become popular in the modern art of designing Francis turbine runners. It is the speed of a runner which is so proportioned, that it develops unity power at unity head. It is defined by the following formula:

$$N_s = \frac{N\sqrt{hp.}}{H^{5/4}}, \text{ or } \frac{N}{\sqrt{H}} \cdot \sqrt{\frac{hp.}{H\sqrt{H}}}, \text{ or } N_1\sqrt{hp._1}$$

N_1 represents the revolutions per minute at unit head, and $hp.'$ the horsepower at unit head. The formula is free of dimensional values and as it contains only the fundamental operating data such as speed, power and head, it permits of the quick determination of one of the four quantities, when the other three are known.

The three values, speed, power and head, can be replaced by dimensional values. The formula thus transformed is free from the first data. Thus we have $N_s = A^*. \ \mu^x \sqrt{V_2{}^x} \sqrt{e} \sqrt{\frac{B'}{D}}$, or $N_s = C\sqrt{\frac{B_1}{D}}$ in Fig 12, C being a constant, containing also the peripheral speed, and the radial inlet velocity of the water entering the effective area "$B'. D. \pi$" of the runner, together with the efficiency of the runner. For impulse wheels, the specific speed $N_s = C'\frac{d}{D}$. is directly proportional to the ratio of jet and impulse diameter of the buckets.

$^*A = \dfrac{60.\ (2g)^{3/4}}{\sqrt{\pi \cdot \sqrt{\dfrac{j}{m}}}}$ and A metric $= 4.45A$. English system.

m = meter $kgm.$ (foot pounds) per 1 $hp.$
j = weight of one cubic meter (foot) of water.
g = acceleration in meter per sec. (foot per sec.).

The specific speed, therefore, varies directly, or with the square root of the following values:

Peripheral speed coefficient, μ^x.

Radial component of absolute inlet velocity of water into runner, V_r^x.

Efficiency of the turbine, e.

Ratio of width to inlet diameter of runner, $\frac{B'}{D}$.

It can be readily seen that the range of specific speed is very wide. It is a minimum for a low peripheral speed of a narrow runner of large diameter, and a small entrance angle α, since $V_r = V$. Sin. α. See Fig. 13 where $V_r = o$ for $\alpha = o$. Particularly so with impulse wheels, where α is a minimum, when the jet impinges directly upon the splitter of the bucket.

Francis turbines with small angles α and a small width B' of the runner invite skin friction, resulting in inefficiency.

The specific speed is a maximum for a high peripheral speed μ^x of a wide runner of small diameter and a large entrance angle α.

According to the values of specific speed we may, therefore, classify the Francis turbines tentatively by:

Type A.	Very low spec. speed....	90	to	110	metric,	20	to	25	Engl.	Fig. 10	a.
Type B.	Low spec. speed..........	110	to	135	"	25	to	30	"		
Type C.	Medium low spec. speed	135	to	180	"	30	to	40	"	"	c.
Type D.	Medium low spec. speed	180	to	270	"	40	to	60	"		
Type E.	Medium high spec. speed	270	to	355	"	60	to	80	"	"	e.
Type F.	Very high spec. speed..	355	to	$>$ 450	"	80	to	$<$ 100	"	"	f.

and the above types are successfully operated under the following limits of heads:

Type A	up to	about	230	meters.	(750 ft.)
" B	" "	"	120	"	(400 ft.)
" C	" "	"	55	"	(175 ft.)
" D	" "	"	27.5	"	(90 ft.)
" E	" "	"	12	"	(40 ft.)
" F	" "	"	6	"	(20 ft.)

In Fig. 14 the above values are shown in an empirical curve and by means of the two formulae given the corresponding specific speeds can be directly computed for both the metric and the English system. The curve represents good up-to-date practice. However, the advancing art strives to apply higher and higher specific speeds to lower heads. The dotted curve

FIG. 12.

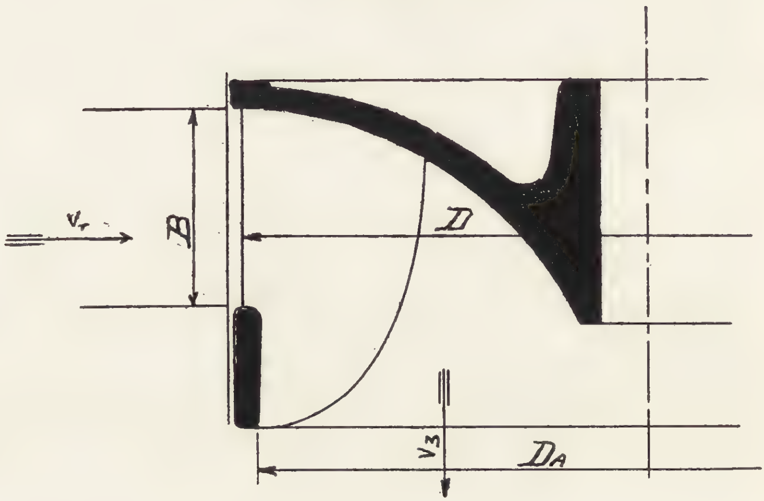
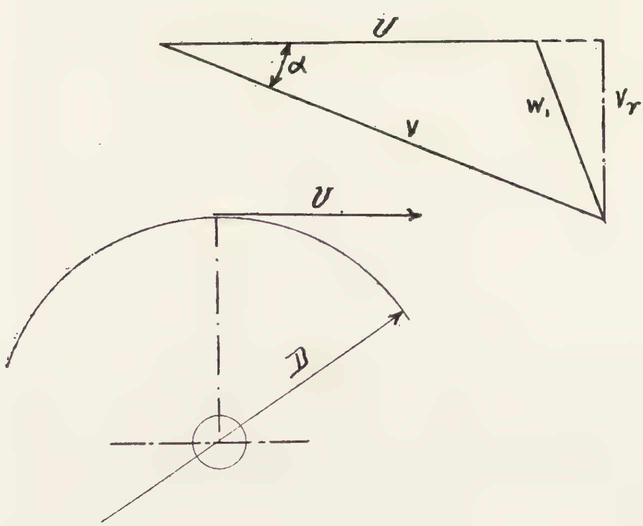


FIG. 13.



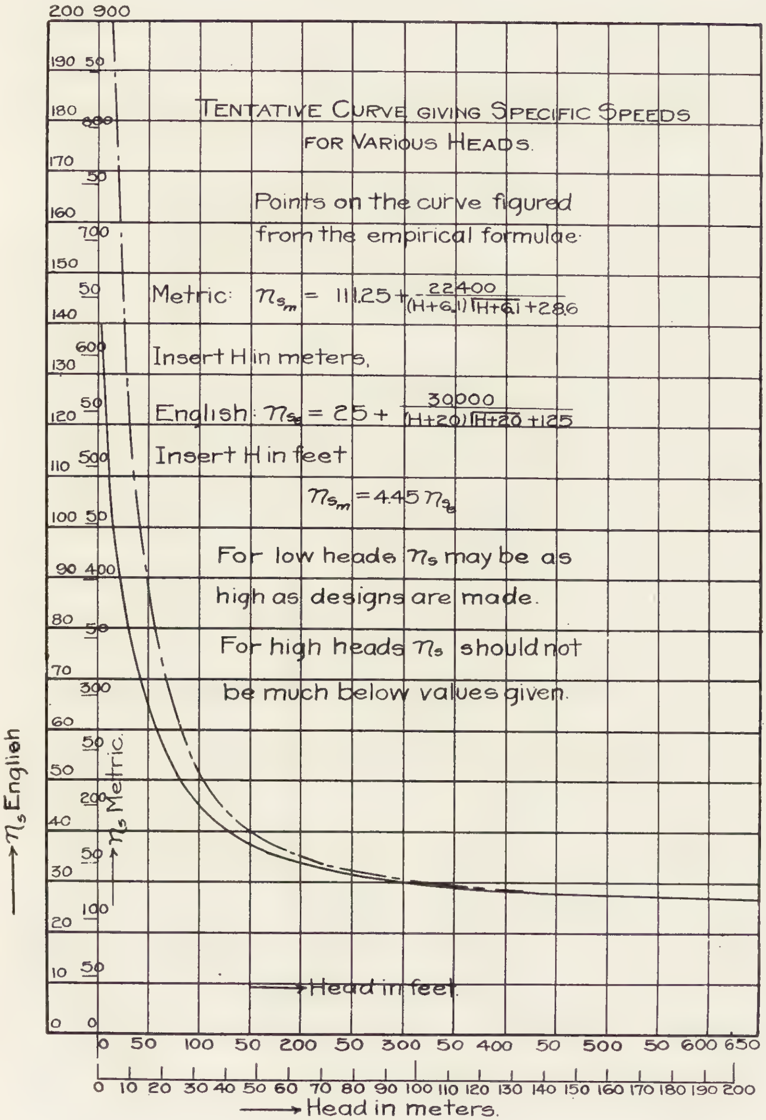

TENTATIVE CURVE GIVING SPECIFIC SPEEDS FOR VARIOUS HEADS.
Points on the curve figured from the empirical formulae.
Metric: $n_{s_m} = 111.25 + \frac{22400}{(H+6.1)\sqrt{H+6.1}+28.6}$
Insert H in meters.
English: $n_{s_e} = 25 + \frac{30000}{(H+20)\sqrt{H+20}+125}$
Insert H in feet.
$n_{s_m} = 4.45\, n_{s_e}$
For low heads n_s may be as high as designs are made.
For high heads n_s should not be much below values given.
→ Head in feet.
→ Head in meters.
→ n_s English
→ n_s Metric.

Fig. 14.

shown is a forecast of what may become the practice and the formulae applying to the same may read:

$$N_s \text{ metric} = 111.25 + \frac{22400}{H\sqrt{H}+21}, \text{ or } N_s \text{ English} = 25 + \frac{30000}{H\sqrt{H}+125}.$$

The size of the runner influences to some extent the selection of the specific speed, particularly when high, as it involves the question of strength at the power developed.

Three runners of a very low specific speed ($N_s = 53$ metric $=$ 12 English) have been in continuous and successful operation for seven years past at the Olmsted Plant, at Provo, Utah, U. S. A. The speed was selected so low, because the wheels replaced an action turbine directly connected to the generator.

The highest specific speeds are found to be commercially developed by American manufacturers, who have been leading in the development of highly efficient runners, thanks to the excellent opportunities for making exhaustive tests, offered by the testing flume at Holyoke, Mass. The world's record in high specific speed is held by Prof. Dr. Victor Kaplan of Bruenn, Austria, with small experimental runners having specific speeds heretofore unheard of. See publication in Zeitschrift fuer das gesamte Turbinenwesen, year 1912, Dec. 10, 20, 30.

(b) Classification According to the Position of the Shaft: Vertical, Inclined or Horizontal Shaft.

Vertical Shafts: Vertical shaft arrangements are favored in low head developments of medium capacity per unit. They are indispensable when large runners are employed. The vertical runner unit is preferably employed where it can be directly connected to its generator or to other energy absorbers. This arrangement has the undisputed practical advantage that the electrical equipment and those parts, such as the governors, thrust bearings, etc., which require more attendance by the operators, can be located on a separate floor and within ready reach of the attendants. In cases where the head, or tail-water level rises considerably, as in times of flood, the advantages cited before become still more apparent, inasmuch as it is possible to locate the generator floor safely above such flood levels, and to allow the hydraulic end, if encased, to be temporarily submerged without causing damage.

Since the vertical unit has its dimensional development principally in a vertical direction, the limited floor space of a vertical shaft plant is very economical, and therefore vertical shaft arrangements may prove advantageous wherever there is only limited space between the river and its bank on which the plant is to be located.

Inclined Shaft: Arrangements with inclined shaft units are infrequent, but may be employed to suit local conditions.

Horizontal Shafts: Wherever local conditions do not exist which render the use of vertical shaft units advantageous the horizontal units have been preferred, perhaps for the following reasons:

Simplicity of and consequently lower cost of power house sub-construction.

Higher speed obtained by using a multiple of runners resulting in lower cost of generating equipment.

Elimination of thrust bearings thus requiring less skilled attendance.

In the past, and particularly in the American market, the keen competition introduced by the numerous stock trade turbines did not permit a careful selection of the type of turbine best adapted for a given installation, but rather allowed the price of the apparatus to be the chief object of consideration. As a result of such a condition, possibly the cheaper layout received first consideration. In the construction, a few piers were put up with a structural iron or wooden frame upon which the turbine was bolted, and often a short stub discharge pipe was used with its end hardly submerged below the tail water or with insufficient clear depth allowed below for an undisturbed discharge. A plurality of single or pairs of runners was used and an extension shaft carried through the bulkhead for connection to the generator. In some cases where the water was supplied by penstocks, a cylindrical steel plate or even cast housing was built around the standard set of a hydraulic unit. With the gradual disappearance of the stock article turbines, it became more and more possible to give the whole plant careful consideration, and to properly arrange the inlet, the flume and the outlet conditions of the unit. Remarkable progress has been made here and abroad, and it has become a

general custom that turbine manufacturers make their guarantees under the distinct condition only, that the flumes, draft tubes, etc., be constructed strictly in accordance with dimensions furnished by them.

European practice seems to favor the horizontal shaft arrangement over the vertical wherever possible and as a result of this, has endeavored to extend the use of horizontal shaft units over as low heads as possible. This has led to the adoption of the siphon chambers, in which the turbines are placed in such a manner that the water level above same may be higher than the head water level itself. An automatic regulation of this level and means for extracting the air from these chambers must be provided. These plants operate satisfactorily but the design has not been introduced into the United States, probably on account of the acknowledged superiority of the single runner vertical arrangement now used here which has been brought to a remarkably high degree of perfection.

The horizontal shaft arrangements for low and medium heads are worked out in numerous ways as has been shown by a publication made in the Zeitschrift für das gesamte Turbinenwesen, 1914, No. 26 and 27, by Johann Hallinger, Muenchen.

(c) Classification According to the Setting.

We may distinguish between the "open flume" and "encased" type of turbine. The highest applicable head of an "open flume" type is limited naturally by the costs of the walls forming the open flume. The remarkable advance brought by the use of reinforced concrete permits of open flume setting for reasonably moderate heads. It is particularly well adapted with hollow dams, such as those of the Amburson type of which numerous plants are in operation all over the globe. The "encased" type of turbine is used in connection with penstocks or in cases where, due to limited space, relatively high velocities are necessary.

Two types of casings may be noted: the cylindrical casing and the spiral casing.

Cylindrical casings are employed with twin turbines with either a common center discharge into one draft tube or with a double quarter turn discharge into two draft tubes. Standard

stock turbines, even of the single runner type, were set into cylindrical casings, all for reasons of competitive cheapness. Cylindrical casings permit of top, bottom, side and end inlet for the water as best meets the location of the incoming penstock. If made liberal, they are wasteful as to the material employed; if made of limited dimensions, they are wasteful in regard to hydraulic losses.

The spiral casing is the most efficient means for bringing the operating water to the turbine. It allows of a relatively high velocity of water without causing losses due to sudden change of direction of the flow, or of the velocity proper. This is due to its characteristic uniform velocities of flow and the fact that the energy contained in the water is correctly employed in the approach to the runner through the guide case.

Three types of construction of spiral casings may be distinguished: The concrete spiral casing, the plate steel spiral casing and the cast (iron or steel) spiral casing.

Concrete Spiral Casing: The application of this type is limited to relatively moderate heads and to units of sufficiently large capacities to justify the additional cost of a spiral casing over that of an ordinary open flume. It is preferably used in connection with vertical shaft units, although also well adapted for horizontal shaft, twin units.

The most efficient type of setting now recommended by progressive engineers and manufacturers is that for the single runner, vertical shaft turbine consisting of a concrete spiral flume. Units of capacities exceeding 10,000 hp. for heads as moderate as 9.2 m (30 ft.) have been placed in successful operation with such settings. Large concrete spiral casings have been used for heads as low as 5.2 m (17 ft.) and as high as 20.7 m (68 ft.). With units of this type, plant efficiencies exceeding 90% were obtained. These high efficiencies were largely due to the proper consideration of all factors involved. It is absolutely essential that all velocities of water from the intake of the spiral flume to the end of the draft tube be harmoniously fixed by dimensions decided upon by the manufacturers of the hydraulic end of equipment.

Steel Plate Spiral Casing: For moderate and high heads, the forces to be considered in the design and construction of

the spiral casing are such that it will be found impossible to further employ concrete. In such cases, a metal casing must be employed.

Cast iron casings, particularly if of large dimensions, are very expensive, a certain minimum thickness of metal being necessary for reasons of the foundry and a division into several parts being necessary for reasons of transportation. With large casings, the item of freight may become of primary importance. Comparing the strength of material of steel plate with that of cast iron, it can be readily seen that the weight of the steel plate casing, built equally strong as a corresponding casing of cast iron, is about one fifth, and it still leaves a higher factor of safety because the steel plate material is more homogeneous than a casting.

Steel plate casings of the spiral form have been built for years past, however, mostly of rectangular cross section areas, an instance being the turbines built for the Niagara Falls, Ontario Power Company, Niagara, Canada. It is evident, however, that the rectangular cross area is neither ideal as to hydraulic nor as to constructive results. Unless very low velocities (resulting in uneconomically large casings) are employed, the losses due to friction, or "dead water in the corners", are considerable. Besides, the flat side walls of the casing are apt to deform unless stiffened considerably by additional angle irons. This design has now been superseded by the circular area spiral casing, which is built up of conical sections either lap-joint, or butt-strap rivetted together. The circular section offers a very smooth and uniform surface to the flow of water and the interior pressure of the operating water imposes uniform stresses upon the material, resulting in uniform and consequently minimum deformation.

These conical sections are rivetted to a speed ring, generally made of cast steel and built up of two flanges held together, within the desired distance, by means of a series of webs which are so shaped and located as to offer a minimum obstruction to the flow of the water, and which take up part of the strain otherwise imposed upon the steel plate sections.

The steel plate spiral casing has been introduced rapidly, due to its acknowledged advantages over cast casings. Its ap-

plication is steadily expanding further into the range of low, as well as high heads. With low heads, its use may be well justified if one considers that a fair portion of a steel plate casing can be made up for the money which must be spent otherwise for building up a wooden form for pouring concrete, and for such steel reinforcements as are indispensable with a concrete spiral case flume. Higher velocities are permissible with steel plate spiral casings due to low hydraulic radius of the sections offered to the water flowing thru same. Hydraulically the concrete spiral casing, being of rectangular cross section areas, may be compared with the older type of steel plate spiral casings. The increasing demand for units of large capacities at moderate heads and the call for a highly efficient, yet simple unit, have opened a wide field for the vertical shaft, single runner, spiral case type of unit, and the advantages connected with a spiral casing, made of steel plate, are so striking that its use is becoming more and more popular. We may mention a typical unit now under construction for the Thompson Falls Plant, at Thompson Falls, Montana, which will furnish power for the electrification of a division of the Chicago, Milwaukee and Puget Sound Railway.

Numerous casings have also been built for horizontal shaft units. They may be free, partly or entirely imbedded in the concrete foundation, as may best suit local requirements.

Cast Iron or Cast Steel Spiral Casing: Cast iron spiral casings are preferably used for small sizes and particularly for horizontal arrangement of shaft. They represent the best known type of high efficiency settings, and have established themselves in practice for long years past.

For higher heads, where water pressure imposes strains upon the material which would necessitate uneconomical thickness of metal, cast steel is substituted for cast iron. The high pressure for which these casings are used produces forces of such magnitude that a careful analysis of all possible stresses should be made with every design. Serious failures are on record caused by lack of proper and scientific treatment of the subject. Above all, the casing should be subjected to a hydro-static test, under a pressure at least 60% in excess of the operating pressure, before it leaves the shop. Care should also be taken

that when subjecting the casing to such a test the pressure should be permitted to impose its strains upon the material exactly as will be the case under actual operating conditions. Shop tests are often made under much more favorable conditions, so that they are worth no more than a showy experiment.

(d) Classification by the Number of Runners Employed.

The speed of a turbine unit varies as the square root of the ratio of the number of runners employed.

Twin, triplex and even quadruplex units have been built for horizontal as well as vertical position of shaft. Sextuplex and octuplex units are found with horizontal shaft arrangement. The possibility of obtaining a high speed for direct connection to a generator may be pointed to as an advantage by turbine manufacturers, who naturally prefer to sell more weight of their own apparatus than leaving the sale of it to generator manufacturers. A careful analysis of the cost of the whole installation and a capitalization of the efficiency, however, reveal the fact that single vertical runner units are by far the most economical. This result is further confirmed by the undisputed fact that a simple, rugged design of a single runner turbine is much more reliable than the complicated apparatus of a multiple runner unit. This fact has already been fully acknowledged by American practice and is being accepted also in other countries.

The geared, or harness type arrangement, has been frequently used. One or two or more single turbines on vertical shafts, set in common or separate flumes, are connected to a horizontal line shaft by means of bevel mortise gears. This arrangement flourished in the times when the standard stock trade turbines dominated the market. By selecting the ratio of the bevel gears, any desired speed of the line shaft could be obtained suitable for direct connection to a standard speed generator. Nothing could compete in cheapness with such layouts, the overall efficiency of which, however, is so low that modern practice cannot consider them any further.

For medium and high heads, the horizontal shaft, single and twin-units are preferred types, except in cases where certain factors, previously referred to, make the use of a vertical shaft arrangement preferable. With turbines operating under

very high head, it is mostly a question as to how a speed can be obtained which is low enough to avoid the expensive design of a high speed (turbo) generator.

The single runner type, of course, is the best. Much fear was manifested at one time about possible failure to properly overcome the end thrust, and the early practice endeavored to solve the problem by splitting the discharge of the runner so that two quarter turn discharges, with two draft tubes, could be employed. A great number of turbines of this type are in operation. The decided disadvantage of this type, however, is that the runner is placed mid-ways between the two main bearings, which are located outside of the quarter turns. The long span, with the principal weight, the runner, in the middle, requires a shaft of large diameter, which in turn takes up a large portion of the passage area of the water discharging from the high head runner at considerable velocity. Hydraulic conditions may arise which set up serious vibrations of the revolving elements, resulting in excessive wear of the parts affected. Besides, considerable hydraulic and friction loss must be expected, due to the relatively large surface offered to the flow of the water at high velocities.

These disadvantages are eliminated with the modern single discharge unit, a design having been adopted which permits of a perfect hydraulic balance of the runner against any end thrust whatever. The runner can be placed directly on the overhung end of the generator shaft, so that the rotating parts of the whole hydro-electric unit are supported in the two generator bearings only. Thus a most compact arrangement is obtained, together with a mechanically perfect alignment of the rotating parts.

Units of large capacity, with moderate head, permit of the use of two runners in order to obtain a suitable generator speed. The twin center discharge unit has been frequently used, two spiral casings being employed with a common center discharge. These units are perfectly balanced, as long as both sides are simultaneously governed. By employing the hydraulic balancing feature, as now used with single discharge unit, it is possible to operate the two sides separately. A loss of efficiency must, however, be accepted in such cases due to

the disturbed conditions in the center discharge. With the twin center discharge type, the shaft and one main bearing are indispensable.

Large units involve considerable initial investment, their revenue should not, therefore, be interfered with by interruption of the operation of the prime mover. Plants which are designed on a basis of conservation of water should be equipped with turbines maintaining good efficiencies even at fractional loads. The operation of high head Francis turbines, at very small loads, may introduce an unfavorable financial efficiency due to wear and tear causing frequent interruption of service for repair. The prime mover of a hydro-electric unit, should, therefore, be so constructed that at least a fair part of the total load is obtained from the generator at all times. This has led to the adoption of the double, overhung Francis turbine, which consists of two independent, single, overhung Francis turbines, one placed at each end of the generator. By equipping each side with its own auxiliaries, such as gate valve, governor, pressure regulator, etc., the whole hydro-electric unit is composed of one generator driven by two independent prime movers. It can be readily seen that such a type is of the highest flexibility in regard to operation and efficiency. One side may have its water supply shut off completely, the overhung runner simply revolving idly in air, or it may be set for a constant gate opening which insures high efficiency, while the other side takes care of the fluctuating load. In cases of repair to one side, the other may be operated for a time until that work is done which requires a complete shut down of the whole unit.

This two-bearing type of unit represents the latest achievement in the design of modern hydro-electric units. It has been rapidly introduced into practice although it is protected by patents controlled by one company only. An 18,000-hp. turbine has recently been constructed to operate under 320′ head at 360 r.p.m. and will be installed in one of the plants of the Pacific Gas and Electric Company of San Francisco, Cal. It will receive its operating water from the Sierra Nevadas, the melted snow of which is stored in Lake Spaulding formed by one of the largest dams built in recent times.

(e) Classification according to the Method of Controlling the Flow of Water.

Old art, cylinder gate, and wicket type of swivel gates.

Out of the great variety of designs for controlling the flow of reaction turbines, only two principal types have been retained in practice, namely the cylinder gate and the wicket or swivel gate type. The cylinder gate type was employed with many of the stock trade turbines, particularly in connection with plants for mills which had a fairly steady load. Later on, the use of this type was also forced upon hydro-electric units, however, with disappointing results. In the early stage of the development of hydro-electric units, a cylinder gate was employed outside of the speed gate, as is shown on Fig. 11 previously referred to. This was a rather crude method of controlling the flow, amounting to nothing more than a throttling down of the operating head, resulting in poor efficiency of the unit. The cylinder gate placed between speed gate and runner is somewhat better, yet it has inherent defects which become manifest in excessive wear and tear of the runner and of parts of the guide vanes adjacent to the cylinder gate proper. This fact is being more and more acknowledged and, therefore, the cylinder gate type will in time yield to the wicket or swivel gate type. The swivel gate was invented as early as 1859 and, as a worthy companion of the Francis turbine, is also of American origin. The credit is due Mr. John Temple, who assigned his invention to the manufacturers of the American wheel at Middletown, Ohio, and later of the new American wheel at Dayton, Ohio. Like the original Francis turbine, the wicket or swivel gate also underwent a number of improvements as a result of the progress of the art. The original invention was first intended for low head developments only and the stock trade-turbines have maintained the same practice up to the present date.

The swivel gate, although a more intricate mechanism than the cylinder gate, offers decided advantages. Wear and tear is greatly reduced for small fractional loads due to fair conditions of flow, resulting also in better efficiencies than are obtained with cylinder gates.

Two types of swivel gate mechanisms are principally used,

the inside type and the outside type. The inside type is the older, and was at first used even for moderate and high heads, but for high heads it has been replaced exclusively by the outside type. With the inside type, all component parts are exposed to the operating water pressure. The guide vanes have a stationary pivot serving as stay bolt between the lower and upper wall of the guide case. They are connected to a common shifting ring by means of links or rods. The shifting ring may be located at the outer periphery of the speed case or at the center portion of the cover plate around the steady bearing. It is either directly operated from one or two reach rods connected to the lever of the regulating shaft of governor or, as was the practice with standard stock turbines, it carries the gear segment operated from the pinion located on the regulating shaft.

The inside type of gate rigging has the decided disadvantage that its principal parts are exposed to the operating water and cannot be inspected during operation.

With the outside type of gate rigging, this defect is substantially eliminated. No parts are exposed to the operating water except the guide vane body and the two adjacent bearings of its pivot. The shifting ring and its connecting elements are placed outside of the operating water where they are readily lubricated and inspected. The decided advantages of the outside type have made its use so popular that it is found for large single runner vertical shaft units even at heads as low as 5.25 m (17 ft.). In case of accidents due to foreign matter lodging between the guide vanes, the inside type suffers considerably greater damage than the outside type. With the outside type, the body and the pivots of the guide vanes can be made sufficiently strong to withstand the entire governor force concentrated upon two guide vanes, if held open by foreign matter lodged between them. This, of course, would prevent the governor from bringing the remaining guide vanes into closed position, so that a runaway of the unit would be inevitable. To prevent this, a safety element is introduced between the guide vane levers and the shifting ring. Several practical solutions are found; for instance, a link designed with a cross sectional area of predetermined breaking strength, or a pin

which is sheared off, both arranged for easy removal. A more expensive but excellent method is the introduction of a spring which is simply compressed or temporarily lengthened until the obstruction is removed. This design is employed by the reputable Swiss concern, Piccard Pictet & Company of Geneva, whose engineers have introduced into practice a number of valuable devices and details which furnish a proof of their eminent abilities.

The outside gate rigging is particularly well fitted for use with high heads, and the latest designs are little short of a high degree of perfection, all surfaces subject to wear and tear being designed so as to be readily renewable with a minimum of expense for their replacement. Spare sets are furnished, made absolutely interchangeable so that such repair work can be done even with the less perfect tools and skilled labor available locally.

SELECTION OF TYPE.

A selection of the type for the conditions to be met in a given installation must not be influenced by two factors which were dominant in early days, viz.:

(1) the existence of designs and patterns previously used,

(2) the customary practice of a country.

The factor first cited may be a highly desirable one from the commercial point of view of the manufacturer or of the nontechnical financier. That tendency certainly dominated during the period when the stock trade turbines were in vogue. That the real engineering end always suffers under its régime is sadly demonstrated in the many financial failures, caused to enterprises which received their advice from parties either incapable of making a proper analysis, or short of the necessary foresight to comprehend the final results. It is a matter of great pleasure to the conscientious and leading turbine designers to notice the remarkable change of conditions during the past decade. It is particularly gratifying to see a country like the United States, at one time practically forced to accept whatever the stock trade market offered, taking the lead in establishing records of highly efficient and reliable designs in the construction of hydraulic turbines.

The customary practice of a country may also be characterized as nothing less than a drawback and hindrance to progress. It may prove interesting to here refer to the many publications which have appeared in European engineering papers, in which over-zealous engineers believed themselves destined to defend the old style, horizontal, multiple runner arrangements against the victorious invasion of the field by the modern, single, vertical shaft units.

It is particularly pleasing to observe again that America has discarded the old customary practice in spite of many warnings sounded by less progressive parties in this country, or by too conservative authorities in Europe, of which the writer could cite numerous examples in connection with his own work. Due appreciation shall be given here to those consulting engineers and manufacturers who have manifested their confidence in progressive designs and constructions and who thus have made it possible for progress to go on unhampered, a fact which has been brought first to public attention in an able paper read by Mr. H. B. Taylor, Mem. A. S. M. E., at a meeting of the Canadian Society of Civil Engineers, January 15, 1914.

Space does not permit the setting forth in detail of the many courses pursued in selecting the type of the turbine. The selection should be based upon a thorough knowledge of the following basic conditions:

First, the extreme operating heads, maximum and minimum, and the head existing for the longest period of the season (variable heads or fairly constant heads).

Second, the topographical conditions of the power site and approaches (pipe line, or open flume, limited area for power house, vertical shafts).

Third, the character of the commercial load (steady or heavily fluctuating load, overload, reserve, and regulation).

Fourth, the characteristic features of the electrical equipment (high voltage, long transmission lines, electrical surges, revolving masses, operating in parallel, etc.).

Fifth, the character of the operating water (presence of glacial silt, mineral acids, etc., requiring special material for certain parts, special designs for ready renewal, etc.).

Comment can be offered on these points as follows:

First, a constant head permits of a runner designed for highest efficiencies at a constant peripheral speed. A wide range of operating head, however, necessitates a design which may sacrifice the highest efficiencies for a greater flexibility under the various peripheral speeds.

Second, power sites with ready access, railroad spurs running into the power house directly below the crane, permit of designs with heavy complex parts, possibly a shipment of completely assembled units. Remote location with wagon or mule transportation necessitates greater subdivision of component parts. Long pipe lines, tunnels, etc., complicate the problem of regulation and may necessitate intricate turbine designs.

Third, a steady commercial load simplifies the device for speed and pressure regulation and permits of a relatively light design of parts affected by the control of the flow of water through the turbine. Heavy load fluctuations impose greater duty upon the gate rigging, runner and governing devices. Special designs and auxiliary apparatus may become necessary.

Fourth, the electrical transmission often introduces factors which require special consideration. Partial and total short circuits, partial runaways of the power system due to failures of governors of other plants operating in parallel may occur which may produce extraordinary operating conditions. Nothing is more welcome in a plant than a simple arrangement and a conspicuous location of those devices requiring quick manual attendance in emergency cases.

Fifth, operating water which is relatively pure permits of the use of standard materials. Impurities in the operating water, which tend to have a corroding effect upon the exposed surfaces, necessitate special materials and require a design which permits of ready renewal of the parts subject to wear and tear. Serious financial handicaps are on record as a result of utter neglect of consideration of these factors. A design causing a large initial investment, but having a low cost of parts to be replaced from time to time, should be preferred over a medium initial cost design with expensive up-keep.

With the above factors given due consideration, and with the other points previously cited in the foregoing chapters, a proper selection of the type of turbine should be possible. There are not many instances where the proverb "Experience is the best teacher" could be better employed than in the designing and building of hydraulic turbines, yet the fact should never be lost sight of that experience only when coupled with scientific research will bring about best results.

EFFICIENCY AND TESTS.

The modern Francis turbine has attained such a high degree of perfection that a proposal with guarantees of efficiency under 80% at full gate, and more so for highest efficiency gate openings, would receive no consideration whatever. A remarkable advance in this direction can be noticed in the past six years. With the single runner, vertical shaft turbine, efficiencies can be obtained which exceed 90%. Such efficiencies have been obtained not only from units tested in special testing flumes but also in actual power house settings. Efficiencies well above 80% were obtained long years ago even with stock trade wheels designed by the so-called method of cut and try, which lacked the proper scientific basis. The increasing demand for turbines of high specific speed has encouraged research work, and the progress made in this direction is the result of an efficient combination of practical experience with scientific treatment of the subject.

Testing laboratories have been installed on both continents by manufacturers as well as technical high schools or universities, and unlimited progress may be confidently looked for.

High efficiencies are certainly very desirable, particularly in cases where the available discharge is limited, yet it does not seem to fully justify the almost frenzied race of over-zealous engineers to obtain and maintain the world's record for high efficiency. Such procedures are apt to bring about unsound conditions in several respects. Designs may be offered which lack consideration of other factors just as important and necessary for the successful operation of a plant. Test arrangements may be chosen in which such intricacies are employed as cannot be fully or lastingly reproduced under actual power house condi-

tions. The logical consequence is that power house results will sooner or later fall behind the result of such show tests. The presentation of results of such a show test may induce those of less experienced judgment to give preference to a bidder although his machinery as a whole may be inferior to that of others, when considered from a point of view of overall commercial results. It may be stated here that as a result of such new practice, the margin between actual results obtained and guarantees made has been much reduced lately, and unless such high guarantees are covered by bonus and penalty clauses they are apt to do more general harm than good.

Let us briefly analyze the values of the various testing laboratories. Testing stations owned by manufacturers are, of course, exceedingly useful to their owners and may be looked on as the proper means of securing the desired progress. Naturally, they are more or less closed to the outsider, and the results obtained remain the private property of the owner.

Turbine laboratories of technical institutions are mostly used for strictly scientific researches, rarely also for purely practical purposes. The results may be considered public property and consequently manufacturers are reluctant in sending their latest products of progress to such places.

To obviate the inherent disadvantage of the two testing stations referred to before, a third kind of testing station may be worthy of consideration, namely, a station at which turbines of any make may be tested, under a responsible management of acknowledged capacity, so that results obtained from tests made at such a station may serve to give information even in cases of a legal nature.

It is again gratifying to note that the United States, even at an early date, took the lead in this direction. Although it is not a testing station which is under the control of the government, the testing flume of the Holyoke Water and Power Company of Holyoke, Mass., is entitled to the consideration given to such a flume. This station, in its first stages, was built as early as 1871 and 1872 and was open for public use and continued under the charge of James Emerson until about 1880. A new testing flume was then designed by Clemens Herschel, the inventor of the world renowned "Venturi Meter" and of

the "Fall Increaser", a recent invention for artificially increasing the suction head on a turbine by means of the surplus flood water. It was completed in 1882, and is in use today under the direction of Mr. A. F. Sickman, Hydraulic Engineer of the Holyoke Water & Power Company.

Space does not permit here of a detailed description of the flume and the methods of the test. The conditions are briefly outlined in the Holyoke Water Power Company's Circular, dated November 1, 1898, an extract of which is here given. "The wheel pit is 20 ft. square and vertical shaft wheels can be tested of any usual diameter and power up to 300 horse power. The weir can discharge about 200 cubic feet per second. Small wheels may be tested under any head from four to eighteen feet; larger sizes from eleven to fourteen feet. The price of test and report is based on the amount of water drawn by the wheel. The test will consist of five or six settings of the gate; additional settings are charged extra. Horizontal shaft wheels, single or in pair, of small and medium sizes can also be tested. All results are kept strictly confidential, report being made only to party ordering the test".

The Holyoke Testing Flume, as it is commonly termed, has served the method of "cut and try" for the empirical development of the standard stock wheels, some 1200 tests having been made up to the end of the past century. It is patronized today equally as much by the leading American manufacturers, and research work on a scientific basis is now done there, as may be seen from the able paper of Mr. Chester W. Larner, read before the American Society of Civil Engineers, August, 1909.

We owe it to the splendid opportunities for testing offered by the Holyoke Testing Flume that rapid advance has been, and is still being made in the development of high efficiency and high specific speed runners of American design. We owe it to the excellent reputation of this Testing Flume and to the commercial reliability of its results that progressive, prospective buyers of Francis turbines have not hesitated to indorse the fruits of such tests by allowing the results to be incorporated into actual commercial design. Much criticism has been heard from European engineers about the reliability of the results obtained from tests made at the Holyoke Testing Flume, to

which the reply may be made, that actual power house tests have in many instances fully corroborated the results obtained at the Testing Flume, both as to capacity as well as discharge and efficiency derived from same, whenever the conditions of test and power house setting of the turbine were as nearly identical as was practically possible. Very recent tests of high efficiency units, where heavy bonus and penalty clauses are involved by the contract, have again conclusively proved that it is perfectly possible to base power house guarantees on Holyoke Tests made with a homologous model runner. The reliability of the results of tests made at Holyoke may be shown again by the fact that in the power house tests, various methods were employed simultaneously for determining the quantity of water discharged (weir measurements, current meter measurements using different types of current meters, salt solution tests, colored water tests, etc.).

As long as the results obtained from such testing flumes check up with the actual power house tests, there is no reason why such a flume should not be most frequently patronized.

ACCESSORIES.

No matter how carefully the selection of the type of Francis turbine may be made and how perfect its design and construction may be found, yet the whole may be proven a commercial failure if the accessories used in connection with the turbine are of either defective design, improperly selected, or omitted entirely. The destruction of complete plants is on record as an exclusive consequence of such defects.

Not including the electrical end in which a number of important factors are involved in the proper combination of hydro-electric equipment, three principal groups of accessories may be briefly referred to.

First—Means for shutting off the water from the flume or the turbine.

Second—Means for controlling the speed.

Third—Means for controlling the pressure of the operating water.

First—The means for shutting off the water from the flume or casing should be placed as close to the turbine as possible

in order to avoid large quantities of water from reaching the turbine after the flow is stopped above. They should also be readily operated from the power house and should, by all means, be so designed, that they can be readily and safely closed against full pressure or head.

For low head units, the gates are usually of the sliding type, although Tainter gates, or some other types of rotating gates, are sometimes employed. Some power house arrangements have only stop logs provided, individual logs being inserted by hand, or complete gates being used, and lowered or raised by a traveling crane running over the entire length of the flumes.

For medium heads, and in cases where each turbine has its own pipe line, a wicket gate, or butterfly valve, may be used as a very satisfactory means for quickly shutting off the water from the turbine. These butterfly valves cannot be expected to be absolutely tight although, if properly designed, they may be sufficiently tight to permit of inspection of the interior of the turbine, provided that a drain is employed for taking care of the leakage water.

Butterfly valves have been used for long years past in Europe and are becoming more popular on the American continent. Two valves each of about 2.125 m (84″) inside diameter under a head of about 134 m (440′) are used in connection with the 22,500 hp. Francis turbines at the White River plant near Seattle, Wash., U. S. A., and are constructed to permit of being closed even in case the turbine or pressure regulator should be discharging its full quantity. Such emergency means, if absolutely dependable, are a valuable protection to the investment and greatly stimulate the confidence of the operating staff in the equipment to be taken care of by them. (See Engineering News, April 18, 1912.)

For very high heads, gate valves should be employed. They should also be designed to permit of their being closed against full pressure, in order to be dependable in emergency cases. A warning may be sounded here against the use of standard designs of gate valves, having a double tapered seat, which permits of a rattling of the valve plug, when partly closed. Serious accidents are on record caused by the failure of such valves

at the very time of the emergency. Reference may be made here to the eight hydraulically operated gate valves, as used for the Big Creek plants near Fresno, California. These gate valves have an inside diameter of 620 mm. (24 inches) and were tested under a pressure of 104 Atm. (1500 lbs. per sq. in.) and were actually closed against full discharge of the units at the power house in order to establish a proof of their absolute reliability.

Second—The speed of a Francis turbine is regulated by the control of the discharge of the turbine. The various types of gate mechanisms have been discussed in a previous chapter.

The gates are actuated by a governor. A relatively large amount of energy is required to actuate the gates, and therefore indirect acting governors must be used exclusively, employing either mechanical energy with the so-called mechanical governor, or a compressed fluid with the hydraulic governors.

The principal requirements for satisfactory governors are:

Reliability, simplicity and sensitiveness combined with steadiness (dead beat action) under constant load.

Reliability and simplicity are inseparable qualities. A complicated piece of mechanism, a delicate or intricate machine, cannot be expected to be absolutely dependable. It requires expert attendance and skill in keeping up the adjustments, etc. Neither one or the other may always be available in power plants.

Lack of sensitiveness of a governor produces variation of speed resulting in poor service. Too much sensitiveness may result in placing unnecessarily heavy duty upon the gate mechanism of the turbine, which increases the depreciation of the equipment.

Not infrequently unsatisfactory speed regulation is due to anything other than the governor itself. In many instances, it is due to lack of proper consideration and knowledge of all factors involved. Past, more frequently than recent, experience revealed the fact that a piece-meal purchase of the various parts of a hydro-electric power plant is greatly responsible for the failure to obtain commercially satisfactory results. Quite often the generator is bought from one party, the turbine from another, the governor from a third, the accessories from standard manufacturers, and the whole utterly fails to be

adapted to producing the desired results. When prices are requested of each part separately, it is natural that each manufacturer endeavors to offer what in his belief will be of such price as will secure him the business. Will a generator manufacturer in such cases take into consideration the character of load and will he add such additional flywheel effect to the revolving parts as may be necessary to secure proper speed regulation?

Will a governor manufacturer include in his proposition other parts which are indispensable under certain circumstances, such as additional flywheel effect of the revolving elements of a hydraulic unit, or pressure regulators, or additional devices for the performance of certain desirable duties?

Will a manufacturer of standard gate valves, etc., offer a design and construction which is dependable under emergency conditions, unless he is forced to do so by purchaser's specifications?

It is not within the scope of this paper to enter into the discussion of the many points connected with the problem of speed regulation. A brief analysis of the practical points of the governor may, however, be in order.

The use of mechanical governors is more and more becoming a thing of the past. They have inherent disadvantages which render their use prohibitive, the larger the amount of energy they are called upon to develop within a certain time. The energy which is produced mechanically, mostly by a belt drive from the prime mover, is delivered to the gate shaft by means of couplings either of the friction type or else hydraulically, and less frequently by means of ratchets which produce a limited gate motion at a time. The rate of the gate motion is constant, irrespective of the severity of the speed fluctuation caused by the load variation. It consists of a series of increments, which, in the case of ratchet connections, may be larger than the gate motion required for readjustment to the corresponding load. The result will be that such a governor will "hunt or race" even under a steady load. Similar defects in speed regulation can be noticed with steam turbines of the action type, where the governor fully closes or opens one nozzle only at a time.

With hydraulic governors, the rate of gate motion varies with the load fluctuation, and the resistance to be overcome according to the lift of the regulating valve admitting the fluid to one or the opposite sides of the regulating piston. Thus a speed regulation can be obtained which is far more accurate than that of a mechanical governor.

The pressure fluid employed is either water, in cases where the operating penstock pressure is sufficiently high, or oil. Water is rarely used in American practice, on account of its wearing effect upon the regulating valve and other parts in contact with same.

A great variety of oil pressure governors are found on the market, some concerns building governors exclusively. Similar to the stock trade turbines, such stock trade governors are made of a certain type and of certain sizes and often their use in connection with different makes of turbines produces the most cumbersome or impractical connections. A specific instance may be cited where the motion of the gate shaft of the turbine was 18° and that of the governor being two full turns, required a train of gears, the total weight and the price of which amounted to far more than that of the governor itself.

The connection between the regulating piston and the gate shaft should be as simple and as short as possible, and should be free from lost motion due to clearances or deformation. With large units, the regulating cylinder is, therefore, separated from the speed governor proper and is frequently placed at a considerable distance from the same for the purpose of obtaining a short and correct connection to the gate shaft or shifting ring.

It is essential that the revenue from large units be as little interrupted as possible, particularly in cases where they operate in parallel with an extensive power system. Provision should therefore be made to enable the unit to be kept under commercial load even in case the governor should be temporarily out of service. To accomplish this an independent, mechanical or hydraulic, hand regulating device should be provided which permits of a ready manual adjustment of the gates of the turbine.

The operation of large power systems, comprising a variety

of hydro-electric, steam, and other plants, requires a well organized management. The load dispatcher generally issues orders to the various plants as to the number of units to be operated and the amount of power to be developed. Plants, which are to economize the fuel, or operating water, are to take care of the load variation, while the others may deliver a fixed amount of power. This brings about the introduction of a number of new features. The orders of the load dispatcher are generally telephoned to the man in charge of the plant, generally the switchboard operator, and to enable him to adjust the load or speed of the unit from the switchboard, the remote control of governor has been introduced. It is a switchboard-controlled motor which operates the relay of the governor, reducing or increasing the gate opening of the turbine. This device also permits of paralleling the unit with the power system.

Sometimes it is required to carry a fixed load irrespective of the load or speed variation of the system and such fixed load may be less than that developed at full gate. It may, for instance, be that load at which the turbine and the generator operate most economically. This requirement necessitates the use of a load limiting device. Crudely, it could be done by simply stopping the piston at the gate opening desired or by forcibly preventing the flyballs from attaining a position beyond that producing the desired gate opening. Correctly, it is done by preventing the distributor of the regulating valve from attaining a position which would allow the gate to open beyond the amount desired. Thus no part of the servo-motor, or of the flyball is strained, and the governor retains the sensitiveness necessary to cause a prompt closing of the gates in case of loss of load.

This fixed load may have to be shifted at times by order of the load dispatcher. A remote control of the load limiting device is therefore the proper solution. It also allows of an adjustment according to the head, or quantity of water available at various times. The first condition arises, when a turbine is designed to develop a certain power under a minimum head and where it would dangerously overload its generator when left to develop full gate load under the high head sometimes existing. The second condition arises, when a plant receives its oper-

ating water directly from a plant above, and when that plant (storage reservoir) has "backed off" with the decreasing load of the system.

The remote control, load limiting device also permits of a very convenient paralleling from the switchboard, inasmuch as it prevents the governor from opening the gates beyond a desired amount at times.

Many hydro-electric units are found which cannot be paralleled when the governor is in operation. They have to be "cut in" by hand and the governor put in operation afterwards, and in case of a dead short circuit, the governor will have to be "cut out" again immediately, to prevent serious racing. This is caused either by inherent defects of the governor, or by lack of flywheel effect of the unit. By means of the remote control, load limiting device, the governor can be made operative before paralleling, and it can be adjusted so as to permit of only friction load gate opening in case of loss of load.

These load limiting devices may also be controlled from floats, thus adjusting the gate opening, or the discharge of the turbine, according to certain elevations of head or tail-water or according to pressures existing in the pipe line.

A few remarks may also be made with reference to the means for delivering the compressed fluid. The efficiency of the pump supplying the compressed oil is a negligible quantity due to the small amount of power required by it. Simplicity and absolute reliability in operation are, therefore, the leading factors in the selection of the type of pump. The rotary gear pump is far better adapted for this service than any other type, due to the absence of any valves or packings, and due to the fact that it consists of the least number of essential parts.

The pressure tanks or accumulators should be of ample capacity and should be provided with protective means to prevent excess pressure. These protective means should be of simple design so as to be dependable.

For large power plants, a central oil pressure system may be adopted, furnishing the compressed oil for all governors in question. Unloading valves are recommended, which prevent the pumps from working against full pressure all the time. A by-pass is opened when a certain oil pressure is obtained in

the pressure tank, and the oil is returned to the receiver tank without being put under pressure. When the pressure has reached a lower limit in the pressure tank the by-pass is closed, and the pump is called upon to deliver the fluid into the pressure tank. The steadier the load, the less oil will be consumed by the governors, and the longer will the pumps be operated under the reduced circulating pressure.

In regard to the question as to what oil should be used, it may be remarked that a governor which operates satisfactorily with any grade of oil, readily obtained within reach of a plant, is much to be preferred over a governor, which requires a certain special grade of oil; and in many instances it may be observed that a high grade governor capable of using ordinary oil, will practically always save its higher cost in a comparatively short period of time, by its economy in the use of a cheaper brand of oil.

Third—With hydraulic plants employing pipe lines, it is of importance to prevent heavy surges of the pressure during the operation, not only on account of possible accidents to the pipe line (bursting or collapsing), but also on account of disturbance affecting the speed regulation. Sufficient literature is found dealing with this particular subject. Three typical cases may be outlined as being caused by the change of the discharge through the turbine, regulated by a governor.

A. Surge with a series of waves of decreasing amplitudes.

B. Surge with continuous waves of constant amplitudes.

C. Surge with waves of increasing amplitudes.

Surges of decreasing amplitudes may not prove detrimental, provided that the absolute value of the first surge does not impose too high strains upon the materials involved, and provided also that the governor is sufficiently static to prevent over-regulation. Surges of constant amplitudes may also be tolerable provided that the absolute values are not serious and that the period of the wave is sufficiently long to permit the governor to follow same aperiodically. Surges of increasing amplitude, however, render the use of a governor absolutely impossible. Numerous plants can be found where the units

must be first paralleled by hand and the governor "cut in" after the generator is "tied" into the power system. The fault may not be with the governor at all, but will be found in the lack of harmony of flywheel effect of the revolving parts of the unit, the velocity of water, and the length of the pipe line. If

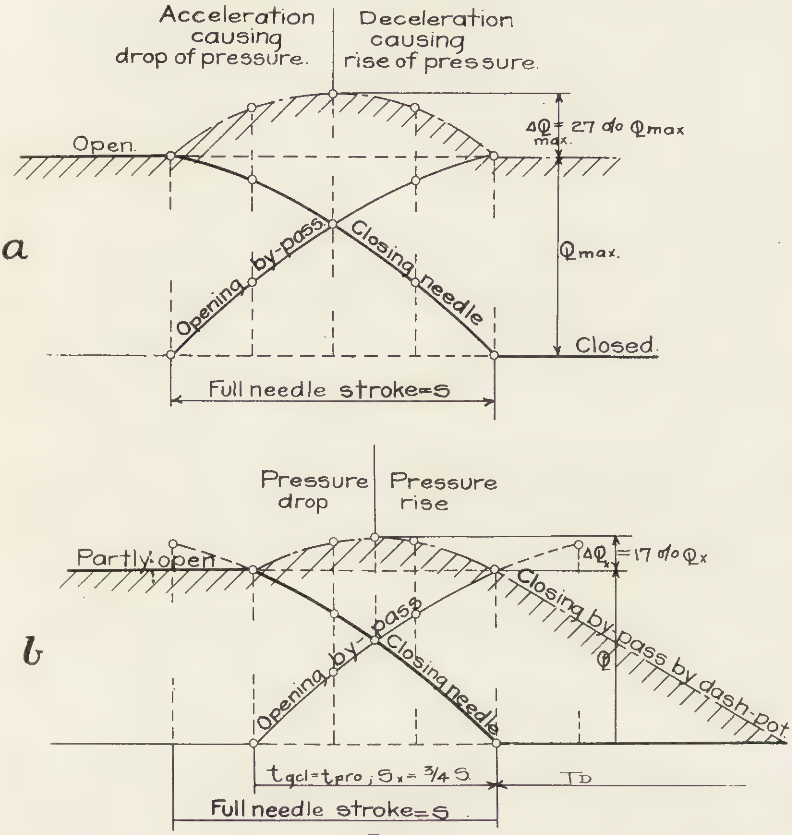


Fig. 15.

one of the three could be properly altered, the trouble could be eliminated. The fact that the governor often behaves correctly, after the unit is paralleled, is explained at once if we consider what liberal flywheel effect is added by the system itself after paralleling the unit.

The velocity, or velocity change, can be reduced by using pressure regulators, and the length of pipe line, or at least its

effect, can be modified by using stand pipes, surge reservoirs, or air chambers.

In cases where a constant quantity must be discharged into the tailrace, the problem of regulation reduces itself to that of an open flume turbine. A synchronous by-pass is used which should discharge exactly the difference between full gate discharge of turbine and discharge at gate opening at times. Thus the velocity in the pipe line is not changed and the effect of the governor is the same as if it simply deflected the stream from the runner directly into the tail race. These by-passes may be directly and mechanically operated, either by direct or by relay connection to the gate mechanism of the turbine, or to the governor itself. It is essential that the rate of discharge of the pressure regulator be inversely equal to that of the turbine under all conditions. If this is not the case, surges will result in the pipe line.

Let us assume two throats of equal size regulated by needles. Their discharge curves follow the law of a parabola of a higher degree, as may be seen in Fig. 15-a. The sum of the area covered by each parabola represents the total discharge during one period of motion and it can be seen that this total discharge of the two throats (closing period of one, and opening period of the other) is about 23% in excess of what is required. The result will be a surge in the pipe line, first caused by an acceleration of the water column and followed by a deceleration. Such devices can be found in actual operation in connection with impulse wheels, and the pressure charts on record confirm the statements made.

In order to obtain absolutely synchronous discharge, it is, therefore, necessary to know the discharge curves as a function of the stroke of the gate mechanism of the turbine, and as a function of the stroke of the bypass valve of the pressure regulator. The rate of the motion of the pressure regulator must then be so fixed that the requirement $Q_t + Q_{pr} = \text{Const.}$ is fulfilled; Q_t being the discharge of the turbine and Q_{pr} that of the pressure regulator for any increment of time.

The operation of a synchronous or water wasting bypass is prohibitive wherever economy of water is essential, as where storage reservoirs are used. The synchronous bypass is made

a water saving pressure regulator by inserting a dashpot which permits of a relative motion of the connection between gate mechanism of turbine and bypass valve. The adjustment of the dashpot is made such that the bypass, after having been opened due to a sudden closing of the gates, is closed within a period which is sufficiently long to prevent a secondary pressure rise in the pipe line. Naturally if the load goes off gradually, and the gates are closed at a rate slower than that produced by the dashpot, the pressure regulator remains inoperative. If the gates are again opened before the dashpot has closed the pressure regulator, then it should close synchronously with the gate motion, otherwise an excess quantity of water is discharged, causing a pressure drop in the pipe line.

Operating diagrams under various conditions are graphically shown in Fig. 16-a, b, d, e, and may be readily understood with the following explanations:

T Equals time of regulating processes.
t_{gcl} Closing time of turbine gates.
t_{go} Opening time of turbine gates.
t_{pro} Equals opening time of pressure regulator.
t_{prcl} Equals closing time of pressure regulator.
T_D Equals closing time of pressure regulator dashpot.
Q Equals maximum discharge of turbine and of pressure regulator.
q_g and q_{pr} At times discharge of turbine and of pressure.

Again referring to the example of the reversing needles, it can be readily seen that if the bypass needle is combined with a dashpot (Fig. 15-b), the relative positions of the two parabolic curves are shifted for each different needle opening at which the governor begins its closing action. Consequently, the character of the surges will be different also. It is, therefore, evident that the requirement $Q_t + Q_{pr} =$ a constant be met also with water-saving pressure regulators, however, only during the period of the gate motion of the turbine.

The total waste of water from the time the load is removed to the time when the dashpot has completely closed the pressure regulator again, may be expressed as follows:

$$W = \int_{t=o}^{t=t_{gcl}} q_g\,dt + \int_{t=o}^{t=t_{gcl}} q_{pr}\,dt + \int_{t=t_{gcl}}^{t=T_D} q_{pr}\,dt \text{ , or}$$

$$W = \int_{t=o}^{t=t_{gcl}} q_g\,dt + \int_{t=o}^{t=T_D} q_{pr}\,dt$$

This amount is equivalent to kilowatt hours and to dollars and cents or equivalent values and is worthy of consideration in connection with the initial expense of an installation, particularly when such a plant is to take care of heavy load fluctuations. More liberal flywheel effect of the units and a larger diameter of the pipe lines may bring about a reduction of the

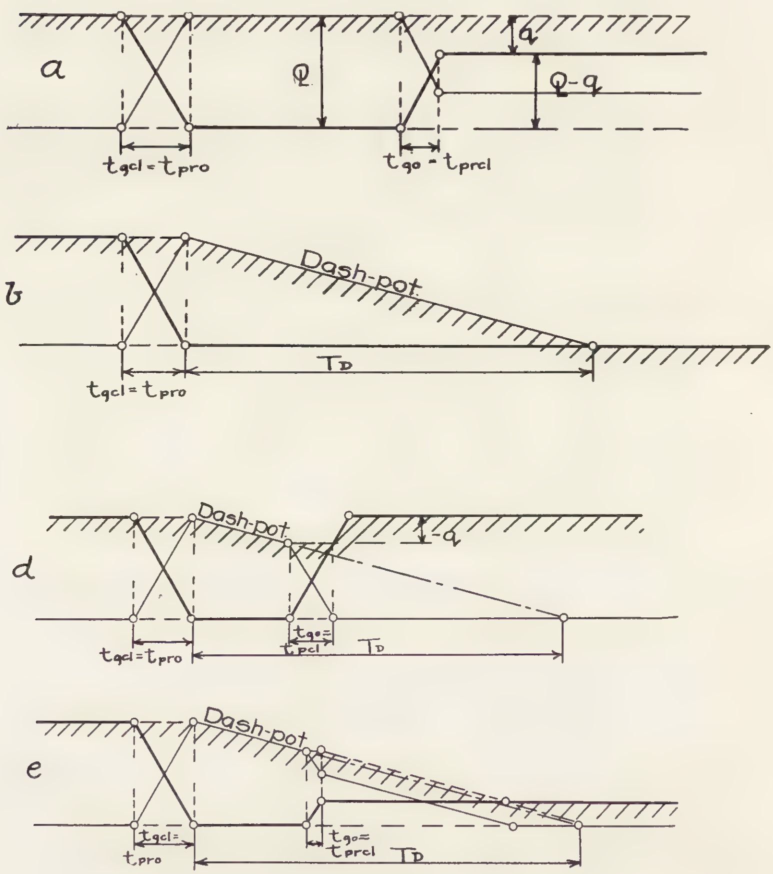


Fig. 16.

above waste which may soon exceed the excess initial investment.

It may be in order to state that a guarantee as to the amount of water wasted during the period of a dead short circuit was made in connection with the 23,000 horsepower impulse wheel units at Big Creek, Cal., the manufacturer of the hydraulic equipment guaranteeing that not more than 850 cubic feet (about 24 cu. meters) of water will be discharged during such a period, at an operating head of 2000 ft. (610 meters).

Water saving pressure regulators are closed during a long period of steady load. They are inoperative when load is thrown on and, therefore, do not assist the speed governor or prevent dangerous surges in the pipe line caused by same.

Two principal types of pressure regulators are used. The governor, or gate co-acting pressure regulator, and the pressure operated, or manometric pressure regulator. The first becomes immediately operative with the closing gate motion, if the rate of same is shorter than that of the closing motion of the dashpot, while the second becomes operative only after a certain pressure rise has taken place. The first has the advantage of responding at once to quick motion of the gates, the latter has the advantage of responding to pressure rises of whatever cause and, therefore, is a more universal means of protection of a pipe line against dangerous pressure rises.

Designs of governor operated pressure regulators, however, are made, which permit of an automatic action also independent of that of the gate motion. This is particularly valuable in cases where there is a possibility of clogging up portions of the gates of a turbine or a nozzle of an impulse wheel. Pressure regulators of such design may be found in successful operation at the Big Creek plants previously referred to.

With hydro-electric units operating in parallel with a large power system the total percentage of load variation is small, and the liberal flywheel effect of all revolving elements of the whole system prevents a sudden drop of speed, so that the governor can open the gates at such a gradual rate as to prevent dangerous pressure decreases. Where this, however, is not the case, and where economy of water is also essential it is

necessary to provide other auxiliary means such as stand pipes, surge reservoirs or air pressure chambers.

Careful analysis should be made of all conditions before determining the size of such auxiliaries. Serious damage has been caused due to improper selection. There is no excuse, however, for such neglect, since sufficient literature is available, dealing with this subject.

The use of stand pipes and surge chambers is often impossible on account of local conditions. Air pressure chambers are costly if of sufficient capacity. Reference may be made here to the air chambers in operation at the White River plant near Seattle, Wash., U. S. A., in connection with the 22,500-hp. high-head Francis turbines. An ingenious communication between pipe line and air pressure chambers has been made, so arranged that the flow from the air chamber to the pipe line is different from that in the reversed direction, the governor- and pressure-operated pressure regulators taking care of the positive, and the air chambers of the negative surges.

Due mention shall also be made here of the so-called Differential-Surge-Chamber, which was successfully introduced into practice by Mr. R. D. Johnson, who has written several valuable papers on the subject. These surge chambers can be found in commercial operation at Niagara Falls, Ontario. They are not only applicable to the pressure side but also to the draft tube side of a turbine. A practical application of the latter type is now being considered in connection with a proposed plant located in the eastern part of the United States.

This type of surge chamber seems to be the most correct and economical solution so far available. Its functioning may be roughly called a hydraulic double compensation, that is, a quick exchange followed by a gradual and finer correction.

SOME GENERAL REMARKS AND SUGGESTIONS.

It is assumed that the papers presented to the International Engineering Congress shall dwell upon their subjects not only from an Engineering or Scientific point of view, but that they may also be of a stimulating nature with reference to general, practical results to be obtained.

Purchasing.

Two or three principal parties are involved when a hydraulic or hydro-electric plant is built.

First: The purchaser, or owner of the property.

Second: His advisor or advisors.

Third: The manufacturer.

The purchaser's advisor may be a consulting engineer, a financier, or an engineering concern, or it may be all in one, himself. There is a difference between a purchaser who has plants already in operation and one who merely desires to build a plant, and to retain it long enough to get things going, just for the purpose of selling out as soon as possible at a good profit. It is easy to guess, which is the customer more desirable to the responsible manufacturer.

The financier's influence may be welcomed by one manufacturer but not by the others.

The services of a consulting engineer will always be beneficial, if he has the capacity to make a proper combination and organization of all factors involved and if he is absolutely independent in his judgment.

Engineering concerns will be most successful if the work is carried out with the main point in mind: namely, to accomplish best general results.

Too much stress cannot be laid upon the importance of the proper selection of the prime mover equipment. Sad examples may be cited where large sums were spent for construction work and where little consideration was given to the seemingly smallest, but most important item, that of the turbines proper. Construction work will stand and may serve its purpose with little cost of upkeep. The prime mover, however, will be the soul of the enterprise, and on the successful performance of its duty depends often the financial result of the entire enterprise. It is gratifying to note that the condemnable practice of giving the item of prime mover least and last consideration is disappearing rapidly, and that careful consideration is now given this portion of work at an early stage of the enterprise.

Much has been, and can still be done in the direction of bringing about still better conditions. Requests for delivery

could often be made more advantageous for the manufacturer as well as for the purchaser by an early letting of the contracts for the prime mover equipment. The quality of the design and construction could be improved by encouraging manufacturers with bonus clauses in the contract. Unscrupulous manufacturers could be gradually eliminated if heavy penalty clauses in the contract held them strictly responsible for failures in meeting the terms.

On the other hand, much expense could be saved to manufacturers and their actual customers, if consulting engineers, or prospectors were less prodigal in their requests for information concerning mere ''wild-goose-chase'' propositions.

This particular practice, and similar ones, should be brought within proper limits by a mutual agreement of all responsible concerns to charge a fee for all such work with the purpose of reducing the burden otherwise distributed over orders received from actual customers.

Let us also touch upon the subject of ''Shopping'', or of playing one competitor against the other, by breaking the news of having ''just obtained'' a new low figure. What is the result? Will it not be detrimental to the interests of the very ''Shopper'' himself? Unless an estimate is made on an unscrupulous basis, the price can only be reduced by an omission of something, somewhere. The picture of the successful bidder is well known. He scratches his head and is afraid to think of what he forgot to include, or is worried as to how he can now make the ends meet on the contract.

Much remains to be done to establish an ethical standard along the above lines, but appreciation is expressed here of those prospective buyers who ask bidders for one price and make it understood that no deviation from same will be considered.

Testing.

In a previous chapter, the question of testing units was mentioned. Manufacturers' testing flumes, as well as those of technical colleges or universities, greatly help the cause, but, however, not sufficiently. The Holyoke Testing Flume is exceedingly valuable, but its range is limited, due to the limited facilities both in regard to head as well as to capacities.

The idea suggested by the Prime Mover's Committee of the National Electric Light Association of building a testing flume accessible to the public and under government control, and of such capacity as to offer a wide range of possible conditions, low, medium, high head, different settings, etc., is an excellent one, and should receive the substantial support of all parties interested, power concerns as well as engineering concerns and manufacturers.

Rating.

A more uniform definition of the various terms such as gross head, net head, effective head, maximum power, normal power, etc., is urgently needed, and a standard should be decided upon and adopted by the engineers of all countries in order to avoid confusion, or legal disputes arising from different interpretations.

Attention may be called here to another specific case:

The energy of a hydraulic governor is generally stated in total foot pounds at a given pressure per square inch (kilogrammeters at a given pressure in atmospheres). Nothing is more misleading, as it may be used by unscrupulous manufacturers of governors with a purpose of deceiving inexperienced engineers or purchasers. A small mechanical governor, for instance, can produce a million foot pounds of energy if it is only given sufficient time to do so. It is suggested here to rate a governor by its maximum torque produced; (PxR) with a given pressure, and also by its "energy produced per second". This latter term is an indication of both the power supplied for, and the rate of the gate motion to be produced by, the governor.

Nomenclature.

A uniform nomenclature should be adopted for use in the literature of the subject. Certain symbols should be selected and used exclusively for one and the same quantities, such as theoretical velocities, relative and absolute velocities, peripheral speeds, etc., and indices should be applied for corresponding values. This would eliminate the tedious necessity of adapting one's memory to the expressions and symbols arbitrarily adopted by each individual.

Above all, a strong appeal may be made here to all engi-

neers and parties of influence to advocate the exclusive introduction of the metric system in practice in all countries which have not as yet shared its blessings.

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Kingsbury and Mitchell Thrust Bearing, **L**, Oct. 10, 1914.

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Miscellany on Turbines.

The Turbines at the Exhibition at Berne, Switzerland (Prof. Dr. F. Prasil), **I**, Sept. 12, 1914.

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Turbines with Artificially Raised Head-water Level, **M**, June 27, 1914.

Concrete Draft Tubes, **L**, Aug. 20, 1913.

Keokuk Runners, **F**, Aug. 21, 1913.

Pitting of Vanes of Water Turbines, **F**, Page 213, Vol. LX.

Packing Boxes with Water Seal, **L**, Oct. 15, 1910.

Labyrinth Seals, **D**, Jan. 21, 1911.

Designs of Shifting Rings on Ball Bearings, **L**, Oct. 19, 1907.

DISCUSSION

Mr. A. H. Markwart,* Assoc. M. Am. Soc. C. E., opened the discussion by reading in behalf of Mr. J. D. Galloway a discussion of the paper of Mr. Pfau, in which he stated that he was interested in the limiting values of the specific speed given by the author. Mr. Markwart.

The range in specific speed from 20 to 100, English units (90 to 450 metric units), shows the wide range in design of modern turbines. The author notes the use of turbines at Provo, Utah, with a specific speed of 12 (53 metric). This is lower than the limit given in the table, and it would be interesting to know if such limits would be considered good practice.

The engineer in general charge of the design of a power plant must necessarily rely upon the engineer of the turbine manufacturer to determine the limits under which turbines can be built. In some cases the extreme is that of a low head, where a high specific speed is necessary. In many other cases, the turbine is being used under relatively high heads, and the tendency is to extend this limit say up to 1,000 feet. This necessarily results in a very high-speed machine. Owing to generator considerations, it is necessary to keep the specific speed as low as possible. It is very much to the credit of American designers that they are able to design turbines which are adapted to this extreme range in specific speed. At the same time, they are also entitled to much credit for increasing the efficiency of turbines until they have reached a point where further significant increase of efficiency cannot be expected.

The author urges the necessity of a uniform definition of terms relating to the subject of hydraulics and the design of water wheels. This is a very pertinent subject. In the design of hydro-electric power plants, three types of engineering come into contact: electrical, mechanical and civil. As all of these different classes of engineers are interested, it would seem that a conference committee should be formed of the engineering societies, to take up the subject and formulate standard rules and definitions.

The Chairman, Mr. W. R. Eckart, Jr.,† Mem. Am. Soc. M. E., called attention, with reference to a point in Mr. Galloway's discussion, to the fact that Mr. Pfau, in connection with the Olmsted plant at Provo, Utah, states that the reason such a very low specific speed of 12 (English) was used was because the wheels replaced an action turbine direct connected to the generator. Mr. Eckart.

Mr. W. A. Doble,†† M. Am. Soc. C. E., remarked that there were several reasons why low specific speed turbines were not used: first, a large runner means a large wetted surface, which intensifies the eddy effect and increases friction; second, the Pelton type of wheel is so far the superior in mechanical construction, that it does not pay to design a Francis turbine for these low specific speeds. Mr. Doble.

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Mr. Doble. In speaking of a merchandizing governor he said that due credit must be given to Nathaniel Lombard, who taught the world how to make a governor which was a commercial machine.

Mr. Martin. **Mr. C. R. Martin*** stated that there are a number of wheels designed for specific speeds of 13 and 14 (English). He thought that Mr. Pfau referred to specific speeds of 20 to 100 (English) as standard practice, while wheels having specific speeds of 12 to 20 (English) could be designed in special cases.

Mr. Streiff. **Mr. A. Streiff,**† M. Swiss Soc. Engrs. (by letter), said that considering the international character of the meeting at which the paper was presented, the author might have pointed out more forcibly the prominent part taken by American engineers in the development of the turbine, which is a source of pride for all engineers in this country.

It is a matter of fact that every marked improvement in the design of pressure-type wheels originated in America. The classic investigations by James B. Francis of his "center-vent" water-wheel at the Booth cotton mill at Lowell in the year 1850 are the foundations of the modern Francis turbine. Professor F. Prasil of Zürich, in his theoretical investigations published in the year 1905, did not hesitate to illustrate his conclusions with examples taken from the original Lowell experiments. It is perhaps not to be regretted that the Francis turbine was not reared in the same scientific atmosphere in which it was born, since this might have stifled the innumerable original creations of the inventors who followed. Each small foundry and machine shop, so to speak, manufactured water-wheels based on Francis' principle, and hardly any new form of runner can be conceived that has not been made in the past, and is perhaps still running in some New England mill. It was not until the year 1875 that the J. M. Voith Company of Heidenheim, Germany, took up the Francis wheel, and in 1876 that the Escher Wyss Company of Zürich, Switzerland, followed suit.

The European designers adhered too much to theoretical considerations, which prevented the development of new forms. It was therefore to be expected that the Holyoke testing flume, which enabled the investigation of new designs, eventually produced the **high-capacity** and **high-speed** Francis turbine, as compared with the former types. This form was originated by a certain Mr. Obenchain, but was taken up and greatly improved by a pattern-maker and millwright, Mr. McCormick, who really must be considered the designer of the modern high-speed runner. All the characteristics of the present high-speed runner are to be found in the McCormick creations. The clearance between guide-vanes and runner entrance is large; there is little flare of the wheel rim, and the outflow velocities are large. It must be ascribed mainly to the extreme values of the outflow loss, coupled with the then not yet discovered regenerating value of a long-taper draft tube, together with a

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tendency for horizontal mountings with defective draft cases, that the McCormick-type wheels did not attain higher efficiencies under practical conditions. Mr. Streiff.

Their practical value, however, in increasing the speed and decreasing the cost of the installation was such that they soon found their way into the European market and caused sharp competition. This led the late Professor Pfarr, who then (in 1902) was connected with the J. M. Voith Works in Germany, to test some wheels of American origin. These wheels were found to be of inferior efficiency (72%) as compared with 80%, and better, which were obtained with the German designs. This investigation led the European engineers to distrust the results of the Holyoke testing flume, which distrust is still maintained today by many engineers, although wholly unfounded. It was but natural that the same wheel tested on a long-taper draft-tube and under a head of 14 ft. in a flume 11 ft. square, as was done at Holyoke, should show a materially lower efficiency if tested in a flume 6 ft. square and under a head of 6 ft. with a short draft-tube. Tests of a wheel with a high outflow loss, with and without draft tube, in the same Holyoke flume and at the same head, have shown a difference of 7%.

In order to refute the claim of these critics that the efficiencies obtained at the Holyoke flume are too high, the Fargo Engineering Company, of Jackson, Mich., introduced the same instruments and methods of water measurement as used in Germany and Switzerland. The screw-type current meter, manufactured by A. Ott, in Kempten, Bavaria, was utilized, and the methods used by Dr. J. Epper, former director of the Swiss hydrometric bureau of Berne, Switzerland, were closely followed. The meters were rated at the naval tank of the University of Michigan at Ann Arbor, under supervision of Professor H. C. Sadler. Dr. J. Epper voluntarily undertook to compute the rating curves from these ratings and pronounced same to be very accurate.

It was clearly established by utilizing these means of water measurements that there is a close agreement between Holyoke and field-test results under similar conditions, and the criticisms of European engineers appear to be wholly without foundation. It is very true that European designers, notably Professor Camerer, by selecting lower outflow velocities, succeeded some twelve years ago in designing higher-speed wheels which gave better results than the American wheels, if not mounted on a long-taper draft tube. For a while it looked as if European design had begun to improve on the American wheels of the McCormick type.

But soon new improvements originated in America. It was recognized, some four or five years ago, that large clearances between guide-vanes and runner entrance were not harmful, but beneficial to increased efficiency and speed. The error into which European designers fell, viz., a small diameter at the entrance, coupled with a large flare in order to get sufficient outlet area, was thereby avoided, and this simple expedient jumped the average efficiency of the high-speed runner five percent

Mr. Streiff.

or more. The smooth wicket-gate design was borrowed from European designers. The single vertical direct-connected unit came into use in very large sizes and became the leading type.

Whereas a great number of power plants in this country, some of which contain the largest size and largest power single-runner units in existence of this latest ''large clearance'' type, have been placed in operation during the last five years, it is only quite recently that European designs, for the third time, follow the example set by American practice. This was fully evident to the writer upon his visit to the Swiss national exhibition in Berne in the year 1914, where a number of specimens of advanced European art in high-speed runner building were exhibited. Compared with the present American turbine industry, which markets runners having a specific speed of 100 (450 metric) with an efficiency of 90%, these European designs were obsolete. On the other hand, it must be admitted that the design of details, such as the guide-vanes, as followed at present in this country, is largely of European origin.

Also, in the field of governor design the most important advance, the invention of the isodrom governor, was made in America, and all the leading governor designs of today may be considered but modifications of the original Lombard governor.

Discussing the future of the reaction turbine, it may be expected that since no material advance in efficiency is possible, the specific speeds will be increased in the future. This future high-speed wheel undoubtedly will be still less a Francis (inward flow) type than the present high-speed runners are, but will undoubtedly be a combination of Fourneyron and Jonval type, without internal guide-vanes, but with a guide-case, as of the present high-speed runners, and a clearance of a quarter circle or more. But even this future high-speed runner will then be an American invention! Mr. Clarence Kinne, Mem. Am. Soc. M. E., of Watertown, N. Y., possesses the prototype of such a futurist wheel, which ran, without guide-case, for years in a saw mill. In appearance it resembles an inverted Francis runner.

The disadvantage of such runners of extreme high speed lies in the fact that the best efficiency rapidly changes with the gate opening. But in our modern hydro-electric stations of larger capacity, the units of which can conveniently be operated constantly at any desired gate opening, this is of minor importance. The Niagara Falls Power Company, for instance, still utilizes cylinder gates, which have a poor part-gate efficiency, for the above reason.

It is also feared that these runners of extreme high speed are not utilizable under high heads, on account of pitting, but there are no theoretical grounds to sustain this objection, because the runners with the highest specific speed have the highest degree of reaction, which is the surest guarantee against erosion. Considering the great advantages they possess in very materially reducing the first cost, this question should

be settled by trial. The proposed government testing flume at Niagara Falls would permit the solution of just such a question. Mr. Streiff.

Mr. Arnold Pfau (author's closure), referring to Mr. Galloway's discussion, wished to say that the curve of specific speeds given on page 458 of his paper should, of course, not be looked at as a steel fence above which (for low or medium heads) and below which (for high heads) disastrous results are to be expected. Modern design of runners on a scientific basis coupled with wide experience enables a remarkable flexibility of design, without inviting trouble resulting from corrosion or crystallization of material due to excessive vibration. It is difficult to define limits, as such limits are naturally limited within themselves, and greatly depend upon the skill of the designer of the runner. For general consideration it is therefore advisable to recommend values which are known to be absolutely safe. Should special conditions justify a departure from such safe values, it is always advisable to consult a specialist, and in doing so it is essential to consult only such specialists who have the real goods to present as proof of their undisputed ability to make proper recommendations. Mr. Pfau.

Mr. W. A. Doble's statement: "The Pelton type (better say Impulse type) of wheel is so far superior in mechanical construction that it does not pay to design a Francis turbine for these low specific speeds" is a rather radical expression of a purely personal and obviously commercial opinion. Recent very careful and conscientious investigations seem to disprove Mr. Doble's statements in more than one respect, and particularly so when a large capacity of the unit is involved.

(1) With a Reaction turbine the whole available head can be utilized. The additional head thus gained is an actual increase of efficiency of the hydraulic development, and in many instances is well worthy of consideration.

With Francis turbines designed to operate under high heads, efficiencies well above 87% have been obtained and have been maintained for operating periods of exceeding five years. No commercial impulse-wheel unit has ever been produced showing operating efficiencies higher than the above-mentioned.

(2) As far as mechanical construction is concerned, nobody will deny the fact that a solid runner casting of steel or bronze is a much safer piece of revolving machinery than a series of buckets individually bolted to a disk. Accidents due to bursting of Francis runners are practically unknown. A fair number of cases of complete destruction of impulse-wheel units (Pelton or Doble type) are on record.

(3) As far as hydraulic wear is concerned, it is evident that such parts as are subject to the flow of water at high velocities will have to be replaced whether the high velocities occur in a Francis turbine or in an Impulse wheel. Records prove beyond a doubt that a Francis runner in a worn-out condition produces at

Mr. Pfau.

least as good an efficiency as does a bucket with a broken entrance edge, a spoiled splitter, or holes through the bowl. A worn-out speed gate (guide vanes and side walls) may cause serious leakage in closed position. It will, however, have no such effect upon the efficiency of the turbine, as can be noticed with a nozzle and needle tip in bad condition of an Impulse wheel.

(4) As to mechanical wear, it can be stated without hesitation that the present high-grade practice enables the production of spare parts which require very little field work. Complex sets may be kept in readiness so that they can be slipped into place in a relatively short time and with the unskilled labor generally available in power plants of remote location. The cost of such Francis turbine spare parts, as well as the expense of the field work involved and the loss of revenue due to interruption of service, will invariably be found less, or at least not higher, than that of a corresponding overhauling of an Impulse wheel.

(5) The first initial investment and the cost of transportation are factors which also deserve consideration. Large generators at relatively high speeds are less costly than generators of equal rating at low speeds. As to weight, a high-head Francis turbine generating unit of large capacity may stand almost the same comparison with an Impulse-wheel generating unit, as a steam-turbine generating unit with a reciprocating steam-engine unit. A similar comparison may be made in regard to floor space, crane capacity, and power house cost in general.

Mr. Pfau is just as interested in the development of Impulse wheels as he is in that of Francis turbines, and he believes that the discussion of such an important subject, viz., the question as to whether Francis turbines should be used or Impulse wheels, should be given careful thought, and that it cannot be disposed of by arbitrary remarks.

In conclusion, he feels that it is to be regretted that the deplorable conditions prevailing due to the war abroad have deprived these transactions of the long range of discussion expected, and expresses the sincere hope that the cooperative work in the development of hydraulic prime movers will be vigorously resumed as soon as peace is restored.

Paper No. 149

WATER WHEELS OF IMPULSE TYPE.

By

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INTRODUCTORY.

The modern development of this type of hydraulic prime-mover dates back to the ''hurdy-gurdy'' water wheel constructed by the early gold miners of California. The history of the wheel will be found in Volume 29, 1899, Transactions of The American Institute of Mining Engineers, Page 852,—''The Tangential Water Wheel''.

The wheel has been designated by several different names, viz., ''Impulse'', ''Impulse-reaction'', ''Free-jet'', ''Spoon-wheel'', ''Tangential'' and ''Pelton'', but in view of the fact that Pelton developed the characteristic dividing wedge of the buckets, and was the first to develop the wheel from the commercial standpoint, the engineering world has adopted the name ''Pelton Wheel'' as being synonymous of the type, as it is a distinct type of hydraulic prime-mover, differing radically in principle from the pressure types and the various forms of partial turbines developed in Europe and in the eastern part of the United States.

EARLY DEVELOPMENT.

In considering its development from 1850 to 1915, it will be best to divide this time into two periods. First, the ''Mining Period'', running from 1850 to 1890, during which time the wheel was developed primarily by the miners, and its principal use was in connection with the mining industry. Its design and development were restricted in merit and quality by the rather crude requirements of the mining industry, and, of course, re-

finements in design and construction beyond the requirements of that industry were not justified. The power of each wheel was also limited to comparatively small horsepower output, as the nature of the driven apparatus was such that there was no call for large power output from a single wheel. During this period the effective head or pressure was comparatively low, averaging from 200 to 500 feet. The power developed by the wheels was necessarily used where it was developed, the length of the transmission being limited to that feasible for a shaft, belt, or rope drive.

Second, the "Electrical Period", running from 1890 to date, during which period, radically new and severe requirements were demanded from the makers of the wheel. The size and power output were no longer limited to the requirements of the immediate location of the wheel, but only by the amount of power that could be developed by the water available. The working head was greatly increased, as new conditions justified greater expenditures in the development of the watershed, with its storage dams, conduits, regulating reservoirs and penstocks. The problem of successful speed regulation to meet the requirement of operating two or more dynamos in synchronism, or two or more widely separated power plants on the same system of transmission and distribution also arose, and involved the necessity of a governing means sufficiently sensitive, accurate and rapid to maintain a uniform speed with instantaneous changes of power demand from zero load to full load and inversely, and with frequent large percentages of the total capacity of the water wheel instantly rejected or applied.

During this period, a further requirement developed, viz., continuous service; whereas, before this period, continuous service, and all that it means, was an unknown quantity. Long distance transmission, reaching out over wide territories and supplying power and light to many commercial industries, towns and cities, gave an entirely new meaning to the term continuous service, and demanded apparatus of the highest type of engineering design, material and workmanship, to meet its necessities.

In the Mining Age, the problem of speed regulation was very simple, since the early use of such wheels was principally to drive

stamp mills, saw mills, etc., where the power output was quite constant and the friction load on the shafting and driven machinery formed a large proportion of the power developed. In such cases regulation was accomplished usually by partially closing the gate valve placed back of the nozzle entrance, or as a refinement, in wheels using a rectangular slot nozzle, a sliding tongue was inserted in the orifice, that could partially or fully open the orifice. A refinement for wheels using a circular jet was the adoption of the deflecting nozzle, to permit of projecting the entire jet against the buckets of the wheel, or partially or wholly deflecting the jet outside the path of the buckets. Other improvements were made, such as in using cast iron instead of wood, etc.; but, in general, it is reasonable to state that the impulse or Pelton wheel of the Mining Period was comparatively crude in its engineering design and in its construction, though suitable for the work it was called upon to do. Many of these early wheels are still in use, and they were of great service to mankind.

During the Electrical Age the development of the wheel by modern engineering methods, such as were in vogue in other types of prime-movers, dates back to the first work in long-distance electric transmission, made possible by the invention and development of the static transformer. This would start the consideration of this later development with the years 1890-1893 with the installation of the Telluride Power Company's Plant, the justly celebrated Pomona Plant, and the plant of the Redlands Electric Light & Power Co. The progress in the art from that time has gone hand in hand with a similar development in the co-related work of the electrical engineer. Thus the hydro-electric prime-mover has brought about a great and rapid development in the water wheel, with its accessories, as it has in the development of the dynamo. A similar development has also taken place in steam-electric prime-movers. New problems in the designing of both types of prime-movers—particularly those connected with safety, reliability and accurate regulation—have thus been brought about by the special requirements of the electric dynamo, with the co-related problems introduced by the requirements of long-distance transmission, continuous service, and speed regulation of a character heretofore unknown, in combina-

tion with the demand for prime-movers of much greater power output, high rotative speed, and to operate under extremely high heads and therefore high water pressures.

Tracing the development from 1890-1893: the Telluride, Pomona, Redlands, and the other early hydro-electric plants quickly demonstrated that the wheel so successful in the Mining Period was entirely inadequate in its design, material and workmanship to meet the more severe requirements of the hydro-electric generating units.

During the period from 1890 to date, there has been a constant development to satisfy the more and more severe and exacting demands of the rapidly growing industry.

To establish a comparison: in the plant of the Telluride Power Company at Ames, Colorado, installed in 1890, were two hydro-electric single-phase units, each of 150 kw. output, consisting of a Pelton wheel directly connected to a Westinghouse generator. These wheels operated under a head of 500 ft. (152 m.).

In the Pomona Plant of the San Antonio Light & Power Co., Pomona, California, installed in 1891, were two hydro-electric single-phase units, each of 120 kw. output, consisting of a Pelton wheel operating under a head of 402 ft. (122 m.) and directly connected to a Westinghouse generator.

In the Mill Creek Power House No. 1 of the Redlands Electric Light & Power Co., near Redlands, California, installed in June, 1892, and first put into operation on September 7, 1893, were two hydro-electric three-phase units, each of 250 kw. output, consisting of a Pelton wheel operating under a head of 295 ft. (90 m.) and directly connected to a General Electric generator. These were the first three-phase generators made in the United States, and this was the first three-phase transmission system to be put into service in the United States.

The development since these early installations has been very remarkable, as will be appreciated in completing the comparison with the more recent developments: there are five or more power plants in the United States where the wheels operate under heads of approximately 2000 ft. (610 m.) and over, and in Europe one plant operating under a head of 2890 ft. (880 m.), and one plant recently completed operating under a head of

5250 ft. (1720 m.), wherein a single jet of water 1½ inches diameter develops 3000 horsepower. The increase in the size of the units is more striking, starting with the 150-kw. units at Ames in 1890 to the recent generators of 12,500 kw. output and driven by Pelton wheels of 20,000 hp. capacity. To fully appreciate this development, it is necessary to consider that it is the result of only twenty-five years' work, which period covers the entire history of the art of Hydro-Electric Power Generation and Transmission.

The details of design of each hydraulic prime-mover are controlled and determined by the natural conditions existing at the location where it is to be installed, and under which it is to operate. These natural conditions and limitations differ over a wide range with every installation; therefore, the hydraulic prime-mover cannot be standardized in design, as is possible with electric generators, steam engines, or steam turbines, but each prime-mover must be specially designed and developed.

The principal controlling factors of the design are: (1) The water quantity curve, or the quantity of water available during each period of each day and throughout the year; (2) the total head that it is possible or profitable to develop; (3) the presence of satisfactory sites, favorably located, on which to construct storage reservoirs, or equalizing reservoirs, from which the pressure pipes will carry the water to the wheels; (4) the character of the load curve that is to be carried; (5) the most economic speed of rotation of the electric generator or driven machinery; (6) whether or not riparian or irrigators' rights have a controlling interest that will affect the possibilities of water storage during the sag in the daily load curve, so as to permit the water not required during this sag in the load curve to be conserved and available to carry the peaks of the load curve. These conditions primarily determine the general type and capacity of the installation, the number and capacity of the separate units into which the plant will be subdivided, the speed of rotation, the method of speed regulation and whether or not water economizing methods can be used to an advantage. These controlling factors differ so materially in each installation that they not only affect the general type or arrangement of the design but also the details.

The general type of unit to be adopted in a given power plant will, therefore, be determined by the particular arrangement and characteristics of details to be incorporated in the unit, as required to meet the conditions under which the prime-mover is to operate; it being appreciated that there are in practically every prime-mover certain similar details, differing only in size and mode of operation.

WHEEL RUNNERS AND BUCKETS.

The term "wheel runner" contemplates the entire wheel proper, consisting of some form of center, to the rim of which the buckets are attached. There are two general types of wheel construction: First, the double-lug bucket; secondly, the chain-type or triple-lug bucket.

The double-lug bucket is arranged with two lugs cast integral with the bucket. The wheel center consists of a single rim. The two lugs of the bucket are accurately machined to a press fit over the rim of the wheel center and the buckets are held in position on the rim of the wheel center by two bolts, which are pressed into reamed holes passing through the two lugs of the bucket and the rim of the wheel center, thus making a very substantial construction. This type of wheel is shown in Fig 1 and the photograph of the De Sabla buckets, Fig. 2.

The wheel illustrated in Fig. 1 is operating under 865 ft. (264 m.) head, at 225 revolutions, and develops 3750 horsepower. This wheel is constructed with a forged steel disc, which is carried on a cast-steel hub with follower plate.

One of the four wheels installed in the Mill Creek No. 3 Plant of the Southern California Edison Company furnishes an interesting illustration of the double-lug type of bucket. This wheel operates under 1900 ft. (580 m.) head at 430 revolutions per minute, developing 1600 horsepower, and has been in continuous service since March 17, 1903. This wheel held the record for some time as operating under the highest head of any wheel in the world. The wheel center consists of an annealed open-hearth steel casting, the buckets being of special hard bronze. This type of construction is thoroughly satisfactory for all installations where the ratio between the diameter of the jet and the pitch

diameter of the wheel is favorable. In this type there are two bolts for each bucket, and where, owing to the large ratio be-

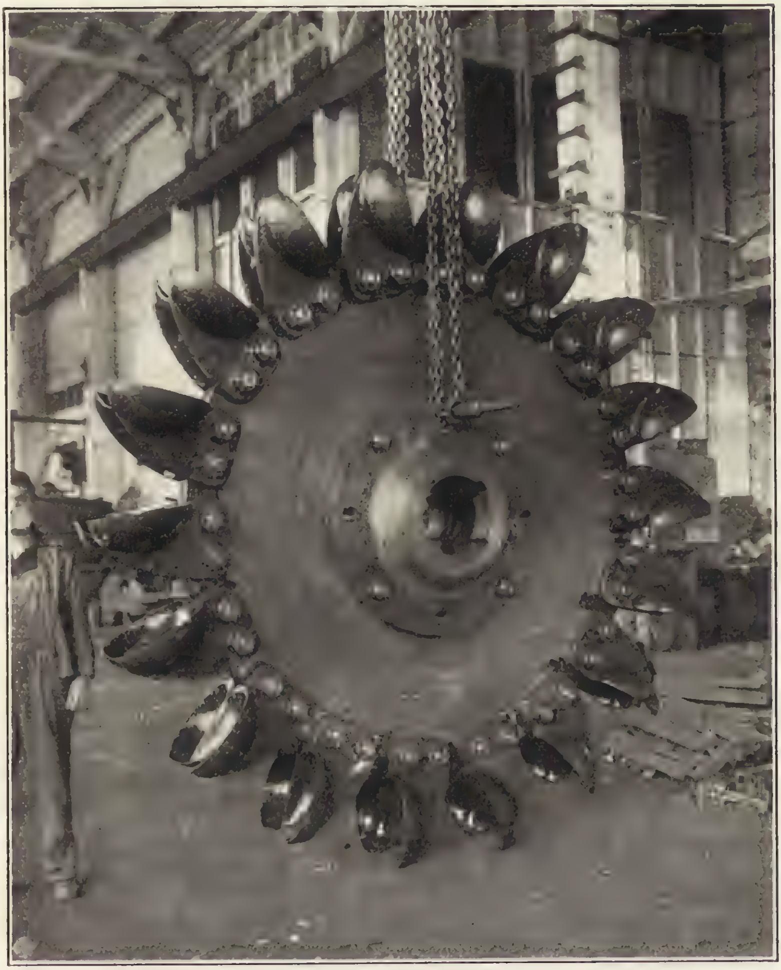

Fig. 1. Wheel of Double Lug Construction, Puget Sound Power Company. Wheel center made from steel forging bolted to a wheel hub with follower plate. Develops 3750 hp. under 865 ft. (264 m.) effective head, at 225 r.p.m.

tween the pitch diameter of the wheel and the diameter of the jet, there is ample room for the two bucket bolts and proper lugs

on the buckets, this type of construction is thoroughly satisfactory.

The photograph of the De Sabla wheel (Fig. 2) also shows buckets of the double-lug type of construction. This photograph is of particular interest, as it shows the condition of the buckets as they were on February 25, 1915, the wheel having gone into service October 22, 1903, and having been in almost continuous service since that time with practically no expense whatever for maintenance. The construction of this wheel shows a forged nickel-steel disc 4 inches thick at the rim and 10 ft. 4 in. in diameter. This forged wheel-center is then bolted directly to a flange forged solid with the hollow nickel-steel wheel shaft. The buckets are made of high-carbon open-hearth steel castings. This record will be of particular interest to engineers as showing what can be accomplished in the way of durability and continuity of service from a properly designed "Pelton" wheel. These wheels operate under 1531 ft. (467 m.) head at 240 revolutions per minute and develop 3700 horsepower.

The chain type of construction differs materially from that of the double-lug construction. In the chain-type construction a double rim is required. This is sometimes made of a wheel with a "U"-type rim. Generally, however, it consists of two separate wheel centers, the hubs being so finished as to bring the space between the rims of the two wheels a proper distance apart. The bucket is provided with three lugs, a forward center lug and two rear lugs. Figure 3 shows clearly the arrangements of the lugs of the bucket. Figure 4 shows the assembled wheel runner complete. These wheels operate under 1330 ft. (405 m.) head at 360 revolutions per minute, and each wheel develops 20,000 horsepower.

In this design the center or forward lug of the bucket is a close fit between the two rims forming the duplex wheel center. The two rear lugs of the bucket straddle the rims of the wheel center, the spacing of the lugs of the bucket and the drilling of the wheel centers being so designed that the rear lugs of one bucket come directly in line with the forward lug of the next following bucket, these holes being drilled and reamed in line. A single bolt therefore passes through the rear lugs of one bucket,

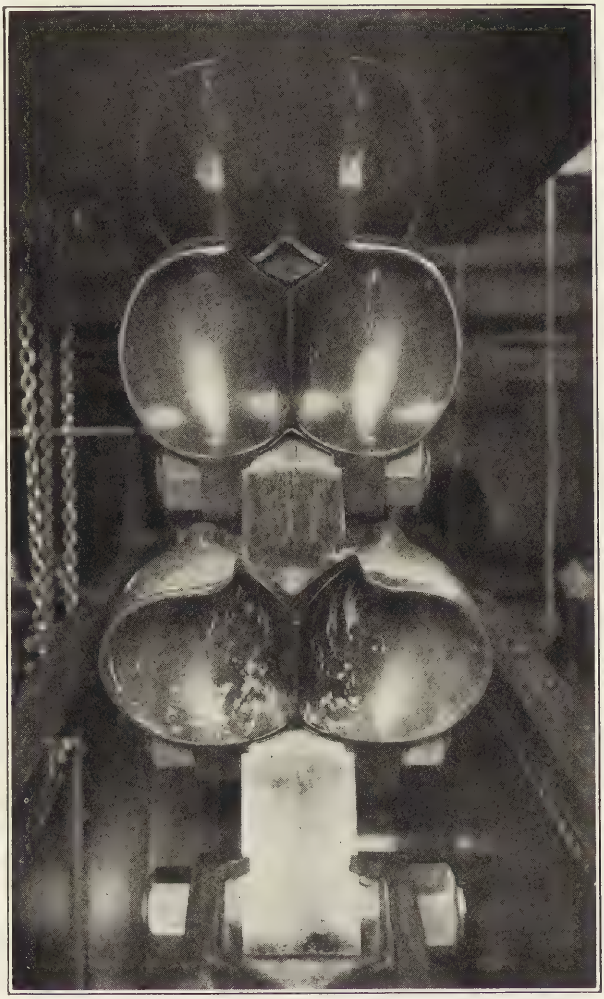

Fig. 2. Photograph Showing Condition of the Buckets on No. 1 Water Wheel at the De Sabla Power Plant of the Pacific Gas and Electric Company.

This wheel operates under 1531 ft. (467 m.) effective head at 240 r.p.m. developing 3750 hp. It was first put into operation on Oct. 22, 1903, and has been in almost continuous service since that time with practically no expense whatever for maintenance. This photograph was taken on Feb. 25, 1915, by the engineers of the Pacific Gas and Electric Company to record the condition of the buckets. The white spots in the bowls of the buckets are due to a mineral deposit left by the water in the buckets in drying. The entire surfaces of the buckets are smooth, the edges of the splitter and entrance edges as shown by the photograph, being sharp.

the double wheel rims of the center and the central or forward lug of the next following bucket, thus connecting up all of the buckets into a continuous chain. By this arrangement it will be observed that there are the same number of bolts as there are buckets, though each bucket is secured to the double wheel rims by two bolts.

In comparing this type with the double-lug type, it will be observed that the base line of the bucket, or the distance between the supporting bolts, is very much greater in the chain-type or

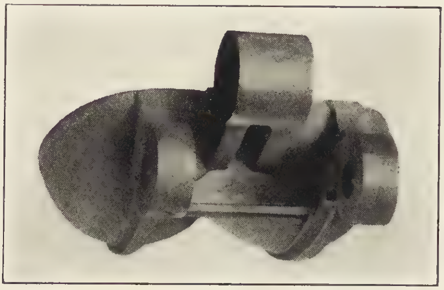

Fig. 3. Arrangement of Lugs on Chain Type or Double Lug Type of Construction.

triple-lug buckets than it is in the double-lug buckets. This type of construction is particularly suitable for all installations where the ratio between the diameter of the jet and the pitch diameter of the wheel is small, that is, where a large diameter of jet is applied to a comparatively small diameter of wheel. This is always the case where a very large power output is required, with a turning speed comparatively high, as proportional to the head of water, thus calling for large buckets on a comparatively small wheel. It is also especially suitable for extreme cases of large horsepower and high heads, making the wheel runner of the most stable construction.

In the construction of the wheel runners for comparatively low heads, cast-iron wheel centers of either the disc or "U"-rim type give good results. For medium high heads, wheel centers of either the disc or "U"-rim type made of annealed cast steel are thoroughly satisfactory. For extreme heads and large horsepower output, the wheel centers should be made from chrome-

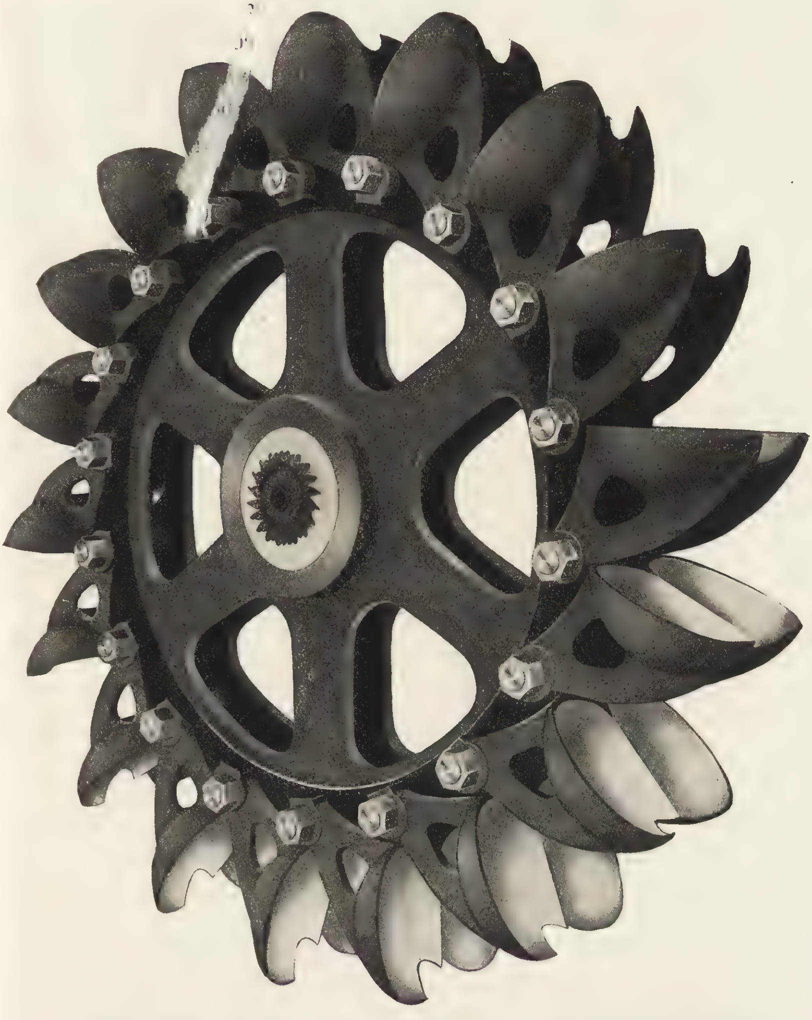

Fig. 4. Wheel of Chain Type of Construction. Wheel center constructed of two separate centers with hubs. Similar to wheels used in the Drum Power Plant of the Pacific Gas and Electric Company, developing 20,000 hp. under 1330 ft. (405 m.) effective head at 360 r.p.m.

nickel steel forgings. In such cases, the attaching bolts are also made of heat-treated chrome-nickel steel and forced into place with 25 tons pressure. The most satisfactory material to use for the buckets is a very high grade high-carbon steel casting. For

the highest heads, it is possible to use drop forgings for the buckets.

In the construction of the wheels, the accurate dynamic balance of the structure is of the utmost importance, and to insure this, the buckets are balanced in a special apparatus which insures a dynamic balance at the maximum runaway speed of the prime mover.

In the earlier wheels constructed, the breaking off of the buckets was one of the principal sources of failure; also the greatest single improvement in efficiency of the wheels was secured by the development of the ellipsoidal type of bucket bowls illustrated in the several photographs, this change alone having improved the efficiency of the wheels by over 10%.

NOZZLES AND SYSTEMS OF CONTROL.

In general, the needle type of nozzle is invariably used, the characteristic jet from a needle nozzle being illustrated in Fig. 5. This is a flash-light photograph taken through an opening in the side of the wheel housing. The blur at the right hand side of the wheel represents the rapidly revolving buckets of the wheel; the cone in the center of the jet is the end of the needle bulb. A characteristic needle and nozzle tip is illustrated in Fig. 6, this being the needle and nozzle tip for the nozzle shown in Fig. 7.

The determining factor in selecting the type of needle nozzle, which also carries with it the means of regulation of the power output and speed of the prime-mover that will be used in a given plant, depends primarily upon whether or not water economizing control can be used. In those plants that are located on streams where water storage cannot reasonably be secured, or where other power plants are located on the same stream, making it necessary to allow the full flow of the stream to pass the plant, or on those streams where irrigators' or riparian rights have a prime control, thus preventing the storage of water, the simpler stationary needle-controlled nozzle with governor deflector control over the jet, or the needle-regulating deflecting nozzle is used. The stationary needle-regulated jet-deflecting nozzle is shown in Fig. 7 (a jet deflector for a

Fig. 5. Characteristic Jet from Needle-Regulating Nozzle. Photograph taken by flash-light through opening in the side of the wheel housing, the blur at the right hand side of the photograph showing the revolving wheel, and the cone of the needle being shown clearly in the center of the stream. The sharp, true cylindrical characteristic of the jet, its transparency and absence of spraying are clearly shown by the photograph.

Fig. 6. Characteristic Needle and Nozzle Tip. Needle and nozzle tips from the nozzles shown in Fig. 7. Jet $10\frac{1}{2}$ inches in diameter.

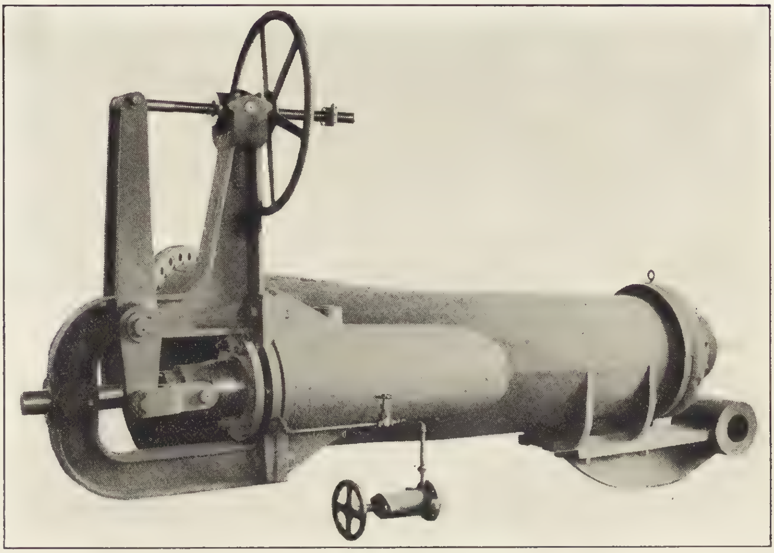

Fig. 7. Stationary Hand-controlled Needle-regulating Nozzle. Arranged for governor control through the means of a jet deflector, this nozzle projecting a jet 10½ inches in diameter.

nozzle is shown in Fig. 8). The nozzle is of particular interest, as it projects a jet 10½ inches in diameter, which is the largest single jet of water used at the present time.

Figure 8 illustrates two nozzles of this type arranged to be supplied with water through a branch "Y" from a single pipe line, the photograph clearly showing the arrangement of the deflector, the hand-operated needle control, and the needle-controlled, reversing water-motor-operated gate valves, one of which is bolted to each of the two discharge flanges of the branch "Y".

The method of mounting the jet deflector is clearly shown. The jet discharging from the end of the nozzle passes through the cylindrical bushing, which is slightly larger than the jet. The speed control is secured by the governor operating on the rockshaft and swinging the deflector more or less, so that it partially or entirely deflects the jet outside of the path of the buckets of the wheel.

The needle-deflecting regulating nozzle is illustrated in Fig. 9. This type of nozzle consists of a nozzle body which

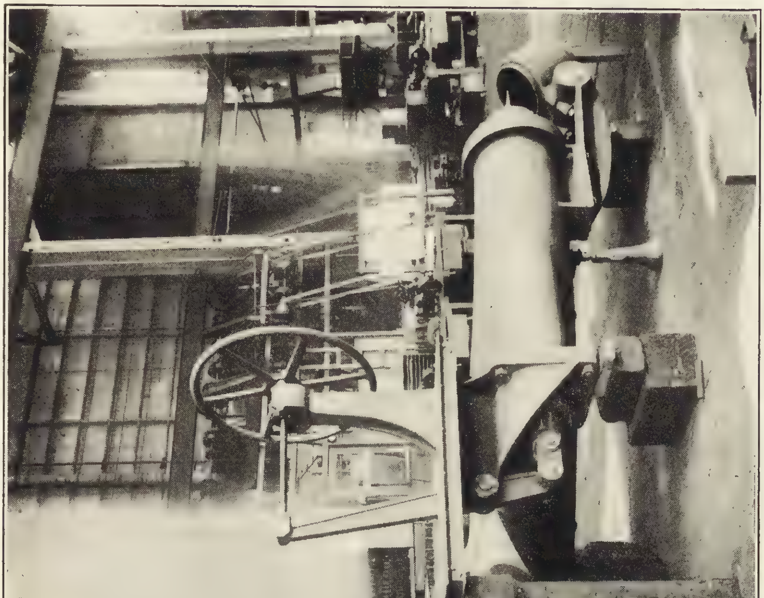

Fig. 8. Arrangement of Two Units to be Driven from a Single Pipe-line with Nozzles of a Stationary Needle-regulating Type. Hand control of the needle, governor control of the jet deflector. Gate valves of the Reversible Water Motor Type. Each wheel developing 2500 hp. under 390 ft. (118 m.) effective head, at 257 r.p.m.

is pivoted to a ball joint, permitting the nozzle to be raised or deflected so as to either direct the full jet into the buckets of the wheel or to partially or entirely direct the jet outside of the path of the buckets of the wheel.

In both the stationary needle nozzle with the jet deflector and the needle-regulating deflecting nozzle, the needle is

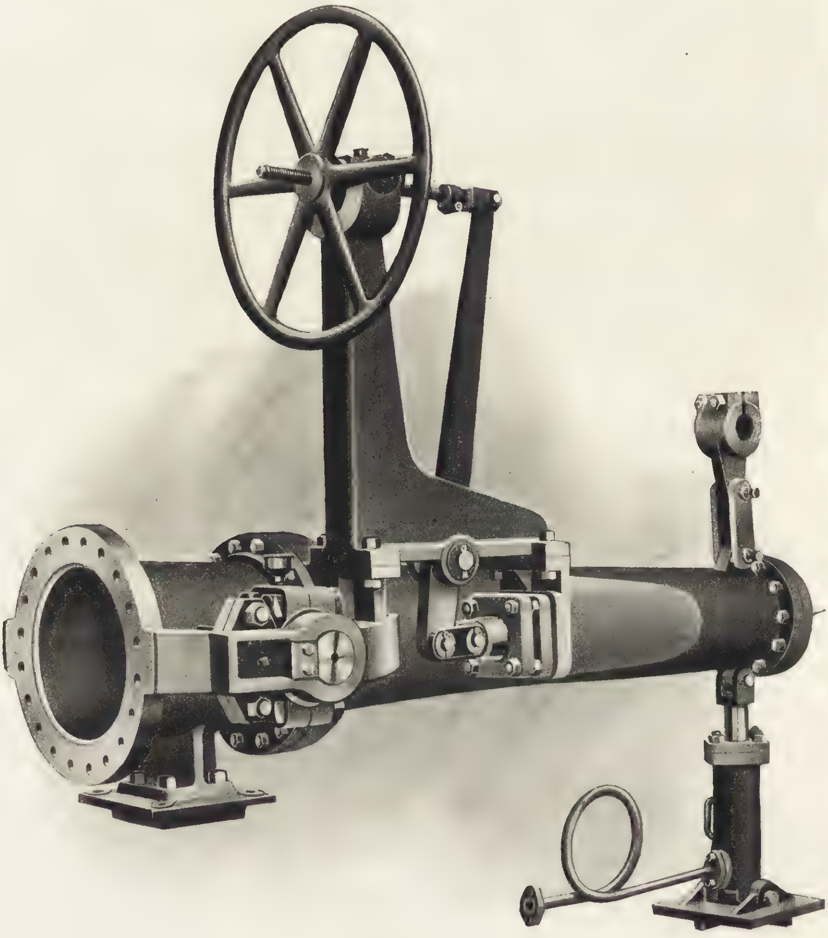

Fig. 9. Needle-regulating Deflecting Nozzle. The needle regulation is by hand control, the deflecting of the nozzle being by automatic governor control with hydraulic counterbalance to balance the weight of the nozzle and the contained water.

usually operated by hand control, the needle being set to utilize to full advantage the available supply of water. In plants where either of these types of nozzles is installed and where there are forebay reservoirs, economy in the use of water is secured by setting the needle at different times during the day to carry the maximum load on the plant, the needle being set to follow the general load curve of the plant, while the momentary load changes and speed control are taken care of by the governor either operating the jet deflector or deflecting the nozzle.

The system of hand setting of the needle with governor control of the deflecting means is of particular value in semi-arid countries where, due to the influence of evaporation, the daily flow is variable to a very considerable degree; and also in those power plants where the source of water supply is in the snow fields, the quantity of water varying to a very great degree, depending upon the melting of the snow by the sun. In such plants the operator can set the needle by hand at different times during the day, to utilize to the best advantage the quantity of water available.

In such plants, where large units are installed, the control of the needle setting is by means of an electric motor with remote control from the switchboard, so that the power plant operator can, from the switchboard, set the position of the needle so as to carry any predetermined load that is desired, the needle setting being changed from time to time as the general condition of the load changes. In such plants the overall consumption of water approximates, in a series of steps, the load curve on the prime-mover. With the needle-regulating deflecting nozzle, the weight of the nozzle with its water contents is counterbalanced by an hydraulic cylinder, to relieve the governor of this additional weight, though the inertia due to the weight of the nozzle and its contained water must be overcome by the governor. Both the stationary type of nozzle with jet deflector and the deflecting nozzle give excellent regulation, for the reason that there is no change in the velocity of flow of the water in the pressure pipe line, due to governor action. Therefore, very sensitive speed regulation can be maintained, as the problem of inertia and the time of acceleration

of the column of water in the penstock is not here a factor in the problem of speed control.

To secure a better economy of water with the use of these types of needle nozzles, automatic devices have been developed so that the governor in rejecting the load on a plant first operates the deflecting means and then brings about a following and gradual re-setting of the needle and nozzle opening. However, these complicated arrangements, at best, are merely adaptations and approximations.

The ideal type of nozzle, and one that has been used in the most important high-head power plants where sensitive speed regulation and the highest economy in water consumption is required, is secured by the needle-regulating nozzle with auxiliary relief-nozzle control, as illustrated in Figs. 10 and 11. In general, this type of nozzle consists of a stationary main nozzle body, the power jet directed against the water wheel being controlled by the needle of the main nozzle. This needle is direct operated by the speed governor, bringing about a re-setting of the needle for each change in power demand on the prime-mover, so that there will be delivered to the buckets of the wheel at all times just sufficient water to carry the load on the prime-mover, thus securing a water consumption by the prime-mover strictly proportional to the power output required from it. By this arrangement, maximum economy in the use of water is secured, taking advantage of every sag in the load curve to conserve the water not required to drive the wheel, in order to have this water available to carry the peak loads.

In the operation of this type of nozzle, to insure against water ram or surges in the pressure pipe line arising out of a sudden reduction of load on the prime-mover, automatically bringing about a correspondingly rapid contraction of the nozzle orifice and retardation in the flow of water in the pipe line, an auxiliary relief nozzle is provided, which is directly connected to and takes its water out of the body of the main nozzle. This auxiliary relief nozzle is likewise provided with a needle control, the jet from this auxiliary nozzle being directed into the tail-race, and at no time brought into contact with the wheel.

The movement of the needle of the auxiliary relief nozzle

is inverse to that of the needle of the power nozzle. This is clearly illustrated in Fig. 10. This inverse action is accomplished by means of the controlling lever, one end of which is connected to the operating means of the governor, the movement of the power needle being secured through link connections between the cross-head on the shank of the power needle and the controlling levers. The lower end of this lever is

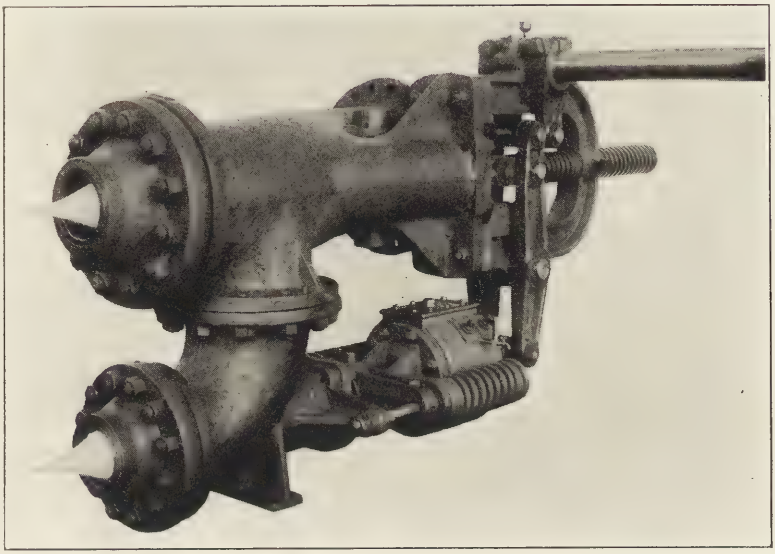

Fig. 10. Typical Arrangement of the Needle-regulating Nozzle with Auxiliary Relief Control. Shows the arrangement of the lever control for the main needle, and control of the relief needle, through the differential-cataract.

attached to a cross-head on the piston rod of the differential-cataract, which is attached to a cross-head on the stem of the needle of the auxiliary relief nozzle. These levers are fulcrummed between the two needle connections. It is evident, therefore, assuming that the differential-cataract be locked in one position, that a closing movement of the needle of the power nozzle would bring about a corresponding opening of the auxiliary relief nozzle, and vice versa. However, such an inverse action is neither required nor desirable, as it would not secure the desired economy in the consumption of water. Therefore, the differential-cataract is introduced between the cross-

head on the stem of the needle of the auxiliary relief nozzle and the lower end of the operating levers.

This differential-cataract is so adjusted that provided a load change is either so gradual or of such an amount as not

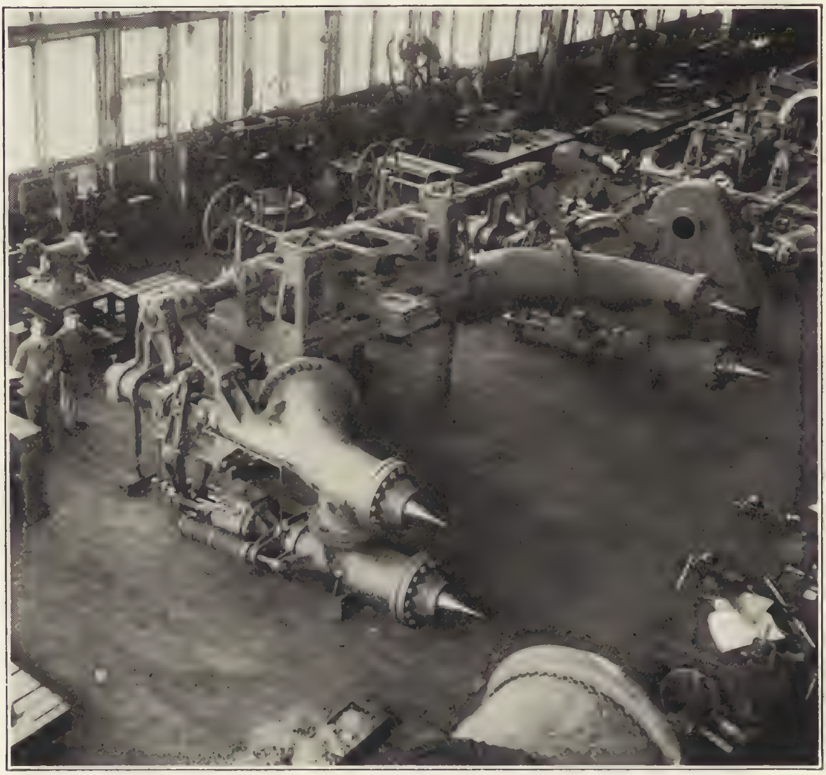

Fig. 11. The Nozzle of the 16,000 hp. Units being Installed in the Power Plant of the Los Angeles Aqueduct. Shows arrangement of auxiliary-needle relief control. Movement of the power needle and the auxiliary-relief needle is controlled from a central governor through a large rockshaft connecting up the governor with both nozzles. Hand control mechanism is provided and arranged so that either or both nozzles can be controlled by governor or by hand. This nozzle projects a jet 8¼ inches in diameter under 870 ft. (265 m.) effective head, developing 16,000 hp. at 200 r.p.m.

to set up disturbances and excessive pressure rises in the pressure pipe line, a yielding or slipping action takes place in the differential-cataract, which permits the auxiliary relief nozzle to remain closed. Under such conditions, therefore, there is no

discharge of water from the auxiliary relief nozzle. In case, however, a load change takes place which brings about a closing movement of the power nozzle of sufficient magnitude to cause excessive pressure rises in the pressure pipe line, or where the load change is very sudden, which would bring about the same results, the time element control of the differential cataract causes the auxiliary relief nozzle to be opened to an amount sufficient to prevent such pressure rises. Immediately the closing action of the needle of the power nozzle has ceased, then the needle of the auxiliary relief nozzle commences to close at a rate which has been adjusted and which will not bring about objectionable pressure rises in the pipe line.

The performance of the needle nozzle with auxiliary relief control is absolute, the movement of the needles of the two nozzles being from the same prime-mover, namely, the servomotor of the governor. This gives an absolute assurance against accidents, and insures the maximum water economy in the operation of the prime-mover with a variable load. The movement of the needles in the two nozzles thus interconnected and operated from the same source of power, insures absolute safety, higher water economy and is more reliable than a governor-operated means of deflecting the jet, and an indirect control over the operation of the needle.

The speed regulation secured by the needle-regulating nozzle with auxiliary relief control is satisfactory for the most exacting conditions. With a proper proportioning of the operating elements, an absolute control is secured over the pressure rises that can take place in the pipe line due to an instantaneous rejection of full load on the prime-mover, which would bring about an instantaneous closing of the needle of the power nozzle. The pressure rises can be kept at any percentage desired, and in special cases a negative pressure rise can be accurately secured with instantaneous closing from full opening of the needle of the power nozzle.

Fig. 11 shows the nozzles for a double-overhung type of unit, developing 16,000 horsepower. These nozzles are arranged with a central governor control, operating the nozzles of the power and auxiliary relief nozzles through the rockshaft extending between the two nozzles. Arrangements are

made for independent hand-control of the needles of each nozzle, should it be desired to operate either one or both sides by hand control. The nozzles illustrated in Figure 11 project a jet $8\frac{1}{4}$ inches in diameter, the head of water at the plant being 940 feet.

The auxiliary relief nozzles are designed to secure a negative pressure rise of over 10% with an instantaneous rejection of full load on the prime-mover. The negative pressure rise with sudden rejections of large proportions of the load improves the speed regulation of the prime-mover.

The latest development in large prime-movers equipped with the needle-regulating nozzles with auxiliary relief control is to mount the servo-motor of the governor directly on the power nozzle, the piston of the servo-motor being mounted on the stem of the needle of the power nozzle. The controlling elements and pendulum head of the governor are mounted directly on the nozzle. This construction is illustrated in Figure 12. A comparison of the design in Fig. 12 and the nozzle arrangement as shown in Fig. 11 will demonstrate the advantage of this latest development.

By the arrangement of the piston of the servo-motor of the governor directly on the stem of the needle of the power nozzle, the most sensitive regulation can be secured, as all lost motion and delay due to torsion in the rockshafts and lost motion in the connecting elements is eliminated. In units of large power, this is a most important factor.

GOVERNORS.

The modern governor is essentially a pressure oil-operated device, arranged with a speed sensitive element, a servo-motor for operating the regulating elements, pilot and relay valves to insure a quick response of the servo-motor to the tendency of speed changes as indicated by the speed sensitive element. Modern governors will indicate and correct speed changes of from $\frac{1}{4}$ to $\frac{1}{2}$ of 1%, and are sensitive to a degree permitting a full stroke of the governor to be made in approximately from $1\frac{1}{2}$ seconds' to 2 seconds' time.

Governors are of two general types: One where the gov-

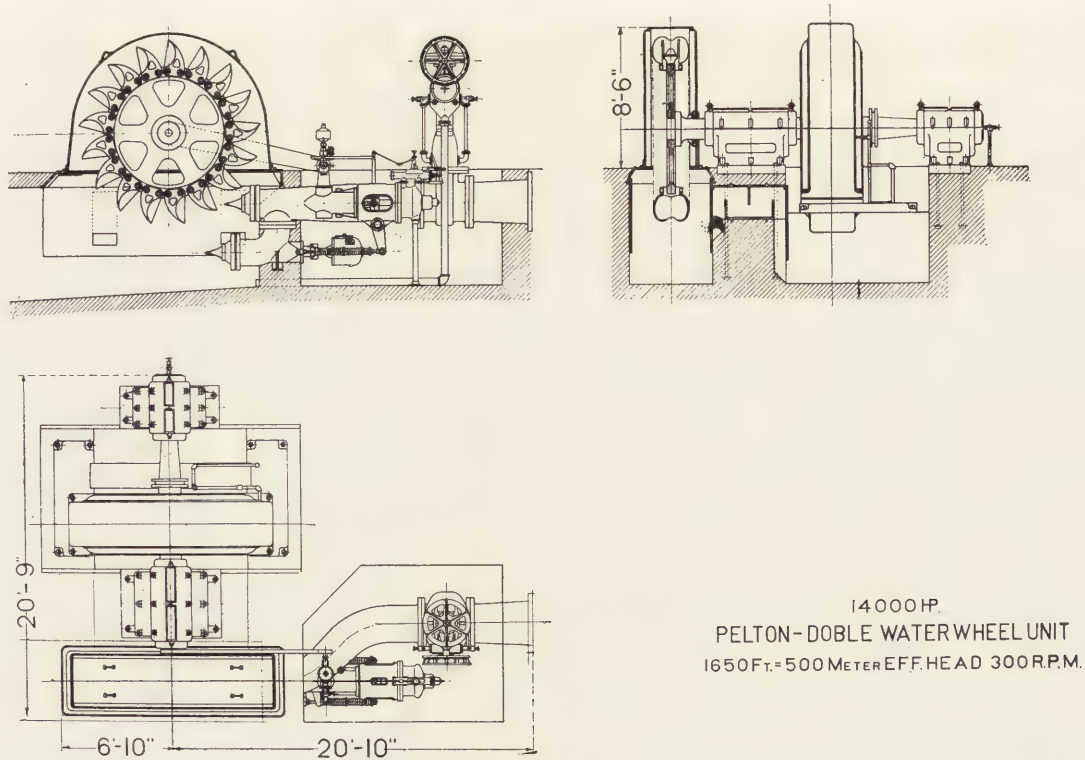

Fig. 12. A 14,000-hp. Horizontal Type Single-overhung Unit with Auxiliary-relief Control. Servo-motor of governor mounted directly on the nozzle body and directly controlling the needle of the power nozzle and of the auxiliary relief nozzles. Also illustrates tail-race ventilators. This unit operates under 1650 ft. (500 m.) effective head at 300 r.p.m., developing 14,000 hp.

ernor itself is a completed machine, as a product of separate manufacture, and arranged with a terminal shaft by which the gate or nozzle-operating gearing of the prime-mover is controlled and operated. Governors of this type are practically a stock manufacture, and are sufficiently flexible in design so that they can be satisfactorily connected up to medium and small size units; such a governor is illustrated by Fig. 13. The oil supply for this governor is contained in the base. The oil pressure to operate the servo-motor is secured through means of the gear pump shown. The speed sensitive element operates the pilot valve, which in turn operates the relay valve which controls the oil supply to the cylinder of the servo-motor. The servo-motor is connected to a terminal shaft, to which the operating elements of the prime-mover are connected. The character of regulation secured from governors of this type is thoroughly satisfactory for the exacting demands of hydro-electric power generating stations.

A modification of this type of governor arranged with a vertical terminal shaft is illustrated in Fig. 14. This type of governor is used with vertical shaft Pelton wheels, the terminal shaft of the governor being vertical and extended to the wheel pit, where it operates the controlling elements of the unit. It will be noted that this governor is fully enclosed, the speed element being mounted at the top. The hand wheel at the side is for hand-control, should it be desired at any time to operate the prime-mover in this manner.

Governors for very large units are illustrated in Fig. 15, which shows what is termed a "direct-motion governor", complete with its independent oil pump, oil-air-pressure storage tank, and controlling mechanism. This governor has a capacity of 40,000 ft.-pounds, the speed element and controlling valves being sensitive to a degree necessary to indicate speed changes of 1/4 of 1%. Through the means of the duplex pilot valve and relay valve construction, the governor can be adjusted to make a full stroke in less than 1½ seconds. On actual test, the governor illustrated made a complete stroke in 1.2 seconds' time. However, such rapid moving governors are not required except in extraordinary cases. The principal feature of the design of this

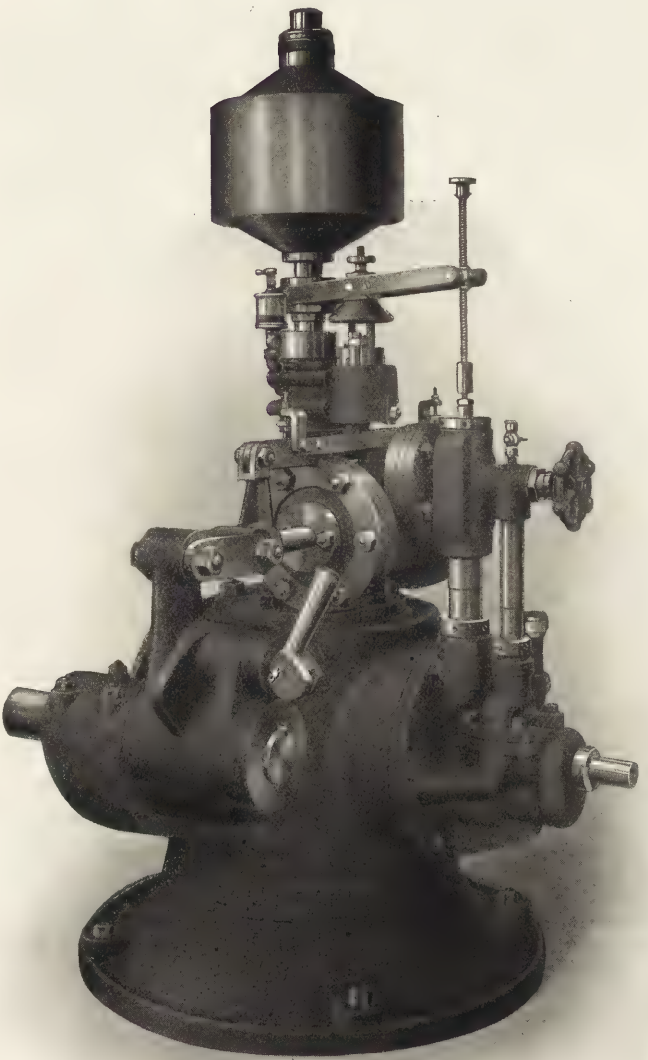

Fig. 13. Standard Type of Oil-pressure Operated Self-contained Governor.

Fig. 14. Special Type of Governor Arranged with Vertical Terminal Shaft to be Used in Conjunction with Vertical-shaft "Pelton" Units.

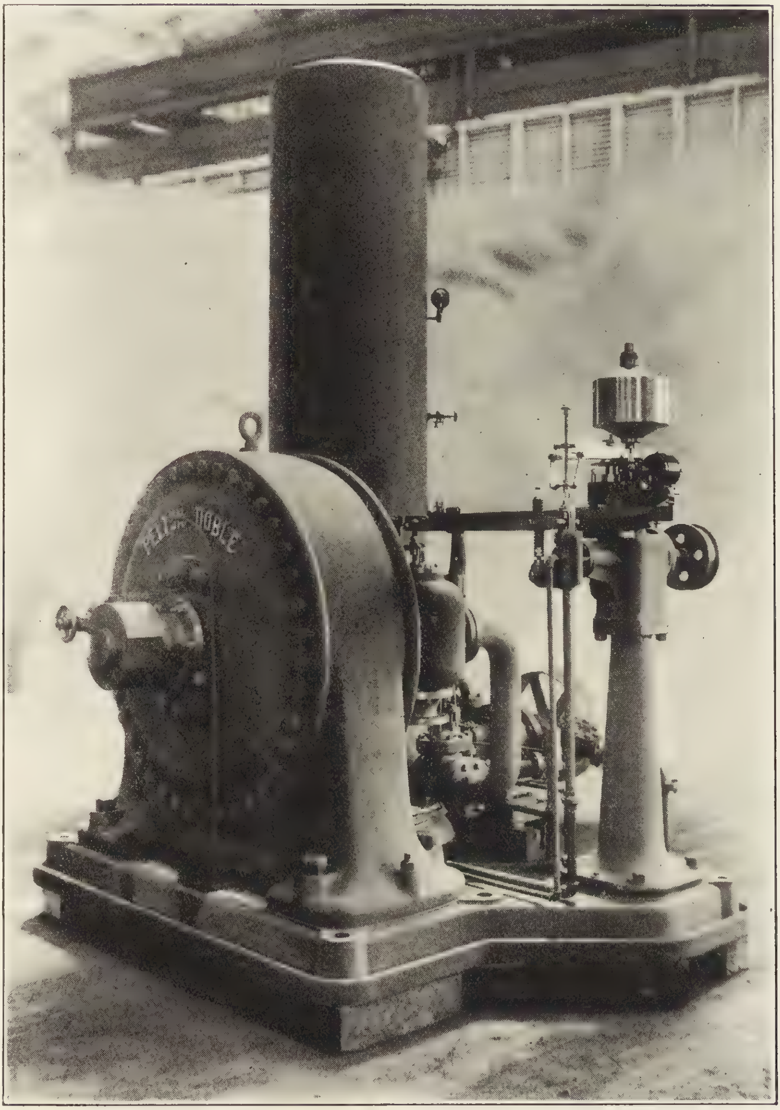

Fig. 15. A New Type Direct-motion Oil-pressure Operated Governor of 40,000 ft.-lb. Capacity, Complete with Independent Oil Pump and Oil-Storage Tank.

governor is that the terminal shaft is connected directly to the oscillating shaft operating the gate controlling elements, thus avoiding lost motion due to linkage connections. To secure the rapid action of this governor, large oil ports are required, necessitating a very large relay valve. This is taken care of by the duplex pilot valve and relay valve construction.

The most recent work, however, in governing apparatus is the direct application of the piston of the servo-motor of the governor to the end of the stem of the power needle. A small governor of this type is illustrated in Fig. 16, this governor being

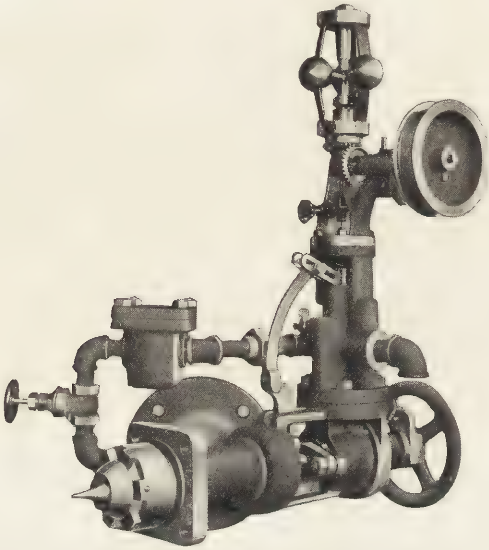

Fig. 16. Small-size direct-motion governor mounted directly on the nozzle body and arranged for water operation.

designed to operate with water pressure, and for this reason a strainer is provided. The same type of governor is also arranged to operate from an independent oil pressure source. Governors of this kind give excellent regulation.

A modification of this type of governor is illustrated in Fig. 17, which shows a 24-inch Pelton wheel arranged for belt drive; speed and power control of this unit are through the means of the governor operating a jet deflector, the needle nozzle being controlled by hand. A modification of this type of unit is illus-

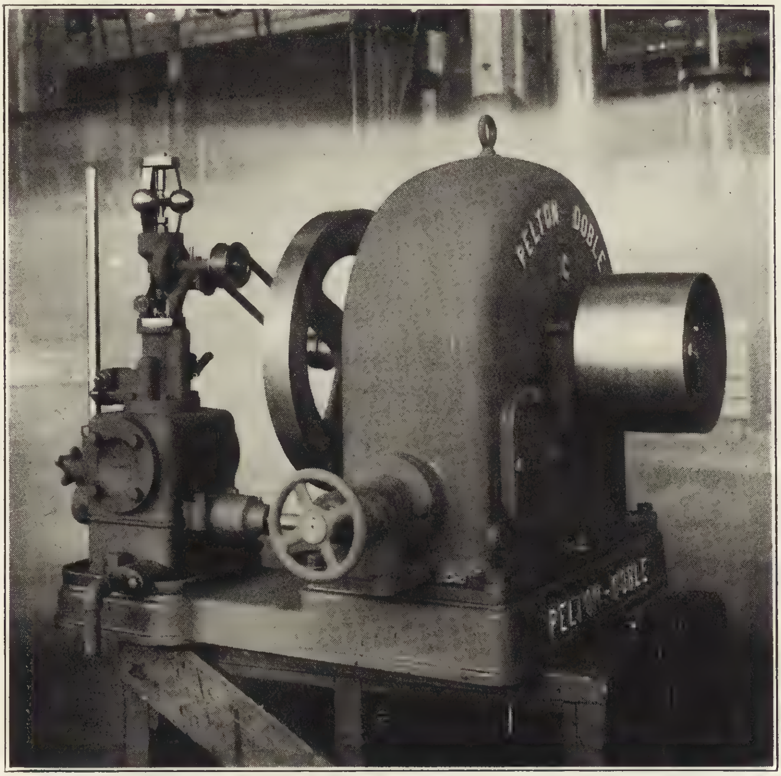

Fig. 17. A Standard "Pelton" 24-inch Water Motor arranged with Oil-operated Direct-motion Governor. Speed and power output of wheel controlled through means of jet deflector. Motor equipped with needle-regulating nozzle hand control.

trated in Fig. 19, which shows a similar wheel direct connected to a 15-kw. generator mounted on a continuous bed-plate. For units of this small size, owing to the insignificant fly-wheel value of the revolving elements, good regulation requires the mounting of a fly-wheel on the shaft.

Excellent regulation is secured from these small units, as will be noted from Fig. 18, showing a tachograph record of a test made on the unit illustrated by Fig. 19. The four upper charts represent the speed control of the governor when instantly applying and rejecting full load on the unit, then three-quarter load on the unit, and then one-half load on the unit. In con-

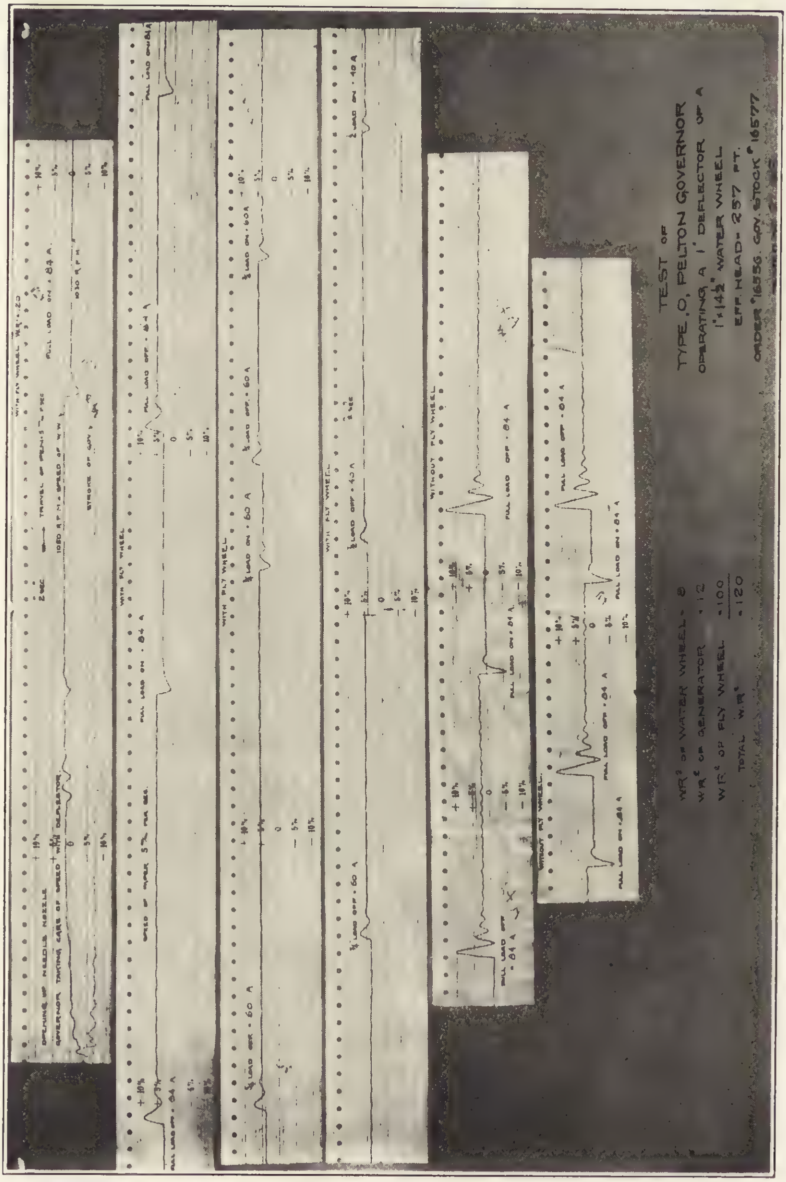

Fig. 18. Tachograph Records on Speed Regulation Test Conducted on Unit Illustrated in Fig. 19.

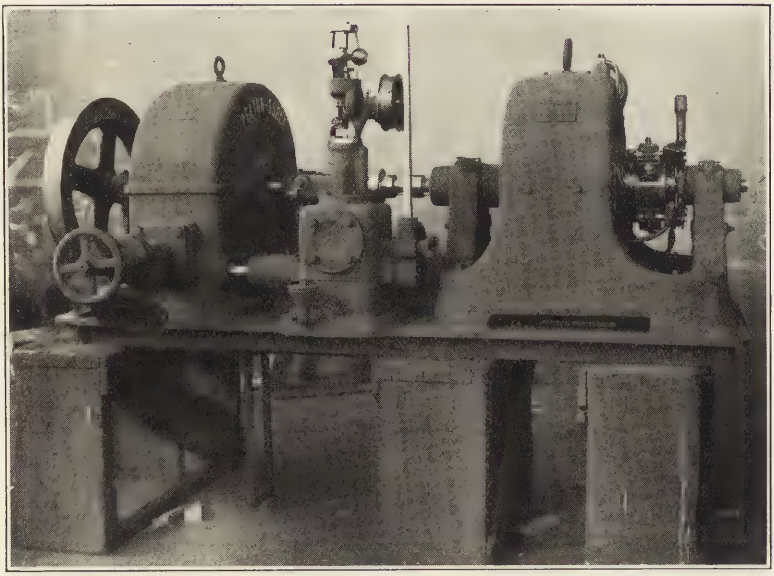

Fig. 19. "Pelton" Hydro-Electric Unit, 15 KW. Capacity. Arranged with direct-motion pressure oil-operated governor operating on jet deflector with needle-regulating nozzle hand controlled. This type of unit is particularly well suited for small isolated plants. This unit operates under 257 ft. (78 m.) effective head, developing 20 hp. at 1020 r.p.m.

ducting this test the load was secured by a water rheostat, the load application and rejection being secured by opening and closing the main switch, thus bringing about an instantaneous change of load condition.

A further test on this unit for governing was carried out by removing the fly-wheel, and the two lower charts show the effect of this change.

MAIN SHAFTS.

In prime-movers of small and medium size, shafts forged from 0.30 to 0.40 carbon open-hearth steel, properly annealed, are thoroughly satisfactory for the purpose. For large prime-movers, however, the shafts should be made from fluid-compressed, chrome-nickel steel ingots, hollow forged and oil tempered. Shafts of this type have now been in continuous service for twelve years. They have proved to be absolutely satisfactory and the bearing journals have taken on a high polish. With the

single-overhung type units, it is preferable to provide the shaft with a flange forged solid with the shaft, the wheel center being bolted to this flange. This makes a thoroughly reliable construction and facilitates erection at the site of the power house. With the double-overhung type, at least the wheel runner on one end must be pressed on to the shaft, so as to allow the shaft to be pressed into the hub of the rotor of the generator; otherwise a very expensive shaft design must be provided, with an enlargement in the center at least as large as the flanges. This construction is not usually justified.

MAIN BEARINGS.

The very heavy weight of the revolving parts of modern large hydro-electric prime-movers together with the high surface speed of the shaft in its bearings have brought about a development of a very massive high-speed bearing. Bearings of this type are illustrated in Figs. 20 and 21. The main bearing shown in Fig. 21 is constructed for a shaft diameter of 20 inches, with

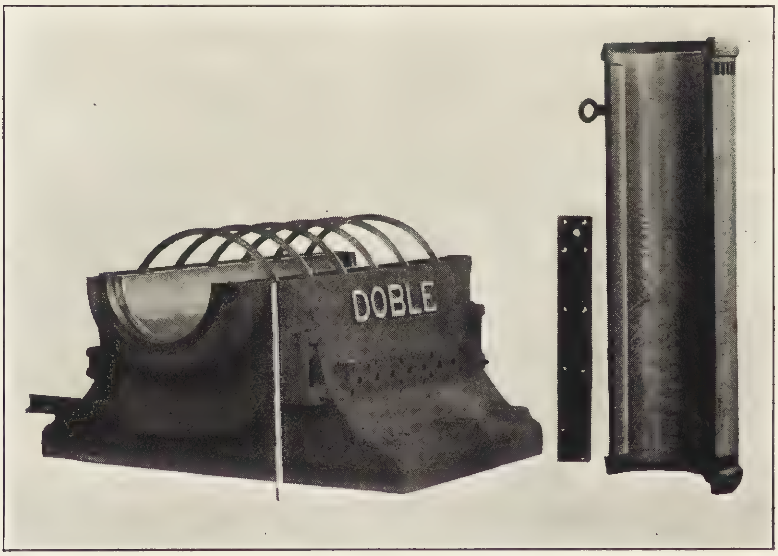

Fig. 20. Heavy-pressure High-speed Bearings. Shows arrangement of lubricating-oil rings, and the construction of the removable revolving shell. Also shows arrangement of water-cooling tubes through oil storage in base of bearing.

a length of bearing shell of 69 inches, the total weight of this bearing as shown being 11,000 pounds. This is one of the bearings of a 16,000-horsepower unit rotating at 200 revolutions per minute.

The bearing surfaces are provided with oil by revolving oil rings, the temperature of oil in the bearing base being controlled by water-cooling tubes. In addition, provisions are made for

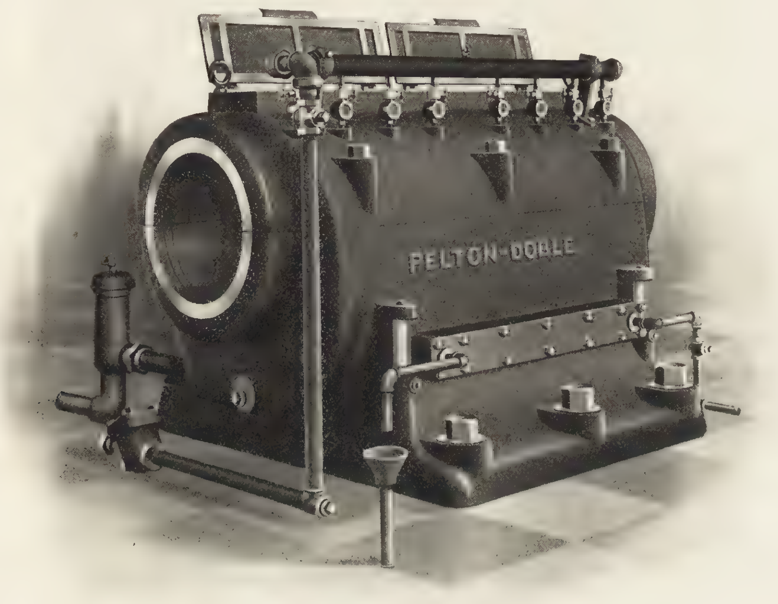

Fig. 21. Typical High-speed Heavy-pressure Bearings. This bearing was constructed for a shaft diameter of 20 inches, with a length of bearing shell of 69 inches. Weight of bearing 11,000 pounds.

supplying fresh oil to the bearing through sight-feed lubricators and drawing out the used oil through an overflow, so that from time to time, while the plant is in operation, the oil in the bearing can be withdrawn and replaced with fresh oil that has been filtered. These bearings are arranged so that the bearing shells can be rotated around the shaft and removed without lifting the shaft from the bearings. They are also provided with air seals at the end of the bearing to prevent leakage of oil from the bear-

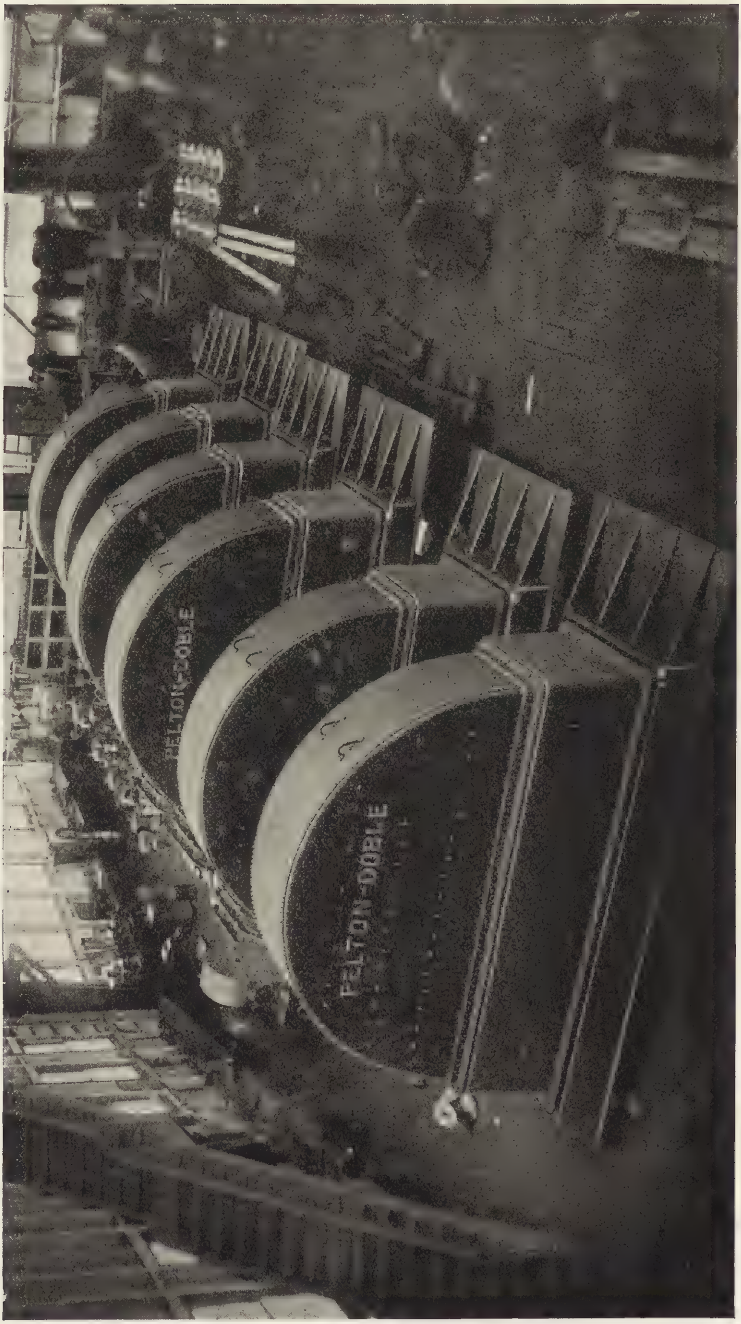

Fig. 22. Typical Construction of Water Wheel Housings for Large Units. These housings are being installed in the power plant of the Los Angeles Aqueduct. Wheels develop 16,000 hp. under 940 ft. (285 m.) effective head at 200 r.p.m.

ings. Hinged covers are provided with ample sized openings, so that the operator can place his hand directly inside the bearings and on the shaft, to check the temperature and condition of the bearing surfaces. Thermometers are also installed in the bearings to indicate the temperature of the film of oil between the surface of the shaft and the surface of the bearing.

A further control of the temperature of the bearing is also secured in large units by discharging a small spray of water through the hollow shaft. This method keeps the shaft cool, is thoroughly satisfactory and efficient, and should always be installed on the largest high-power units. The arrangement for applying the water to the end of the shaft is illustrated in Fig. 12, where, at the end of the shaft opposite to the water wheel, the spray nozzle is shown. Due to the partial vacuum existing in the wheel housing, this fine spray of water is drawn through the shaft, producing thereby a most efficient cooling medium.

These bearings have proved to be absolutely satisfactory under the most severe conditions of heavy pressure and high speed. The older form of so-called spherical self-aligning bearings are not now used on the heaviest type of units.

WHEEL HOUSINGS.

The general type and construction of housing, or casing, in which the wheel is to revolve are illustrated in Fig. 22. For best practice each wheel should rotate in a separate housing to prevent interference from discharged water. The lower part of these housings is preferably made of iron castings, the upper housing, or cover, being preferably made of steel plate riveted into a cast iron frame. The joints in this plate work are riveted hot, chipped and caulked, so as to be water-tight. This type of housing for large units is preferable to a housing made entirely of cast iron, as it is lighter to handle and eliminates any danger of breakage. Where the shaft of the water wheel passes through the side of the housing, leakage of water through the opening is prevented by means of a centrifugal disc and water guard. This device makes a frictionless packing. In small units it is preferable to make the housing of cast iron.

CONTROL GATES.

A very important feature in all hydro prime-movers is the main control gate or valve, the general type in use being of a single-disc gate construction. In the earlier plants hand-operated gates were deemed sufficient. A later development brought about the use of gates operated by an hydraulic cylinder, as shown in Fig. 35 of the Crane Valley No. 1 Power Plant. The latest development in disc gate valves is where the gate disc is operated by a reversible water wheel. A gate of this type is illustrated in Fig. 23. This type of gate has proved more reliable and satisfactory in service than the hydraulic-cylinder operated gate valve, as grit and foreign substances in the water which have a tendency to clog the valves and cylinders of hydraulic-cylinder operated gate valves do not affect the operation of the reversible water motor.

Furthermore, the reversible water motor has a very heavy starting torque, which is of value in commencing the opening stroke of a gate valve which may have remained shut for some period of time, as in such cases there is a tendency for a gate disc to stick to its seat.

In the reversible water-wheel operated gate valve, the main gate stem is provided with a safety limit stop, so that in the opening or closing movement of the gate it protects the gate against stress which would be set up in the structure, due to over-opening or over-closing the gate by careless operation.

For prime-movers operating under the highest heads and where the units are of very large power output, the disc gate valve is not the best form, owing to the enormous pressure brought upon the seats of the gate ring and to the cutting action on these seats due to eddy currents set up in the water passing through the throat of the gate.

The ideal type of control gate for use with the largest size units and under extremely high heads is the "uniform-flow needle gate valve" illustrated in Fig. 24. In the control of water under high heads, it has been demonstrated that the needle type of valve is the proper design to adopt. The construction, as shown in Fig. 24, consists primarily of a needle-regulating valve

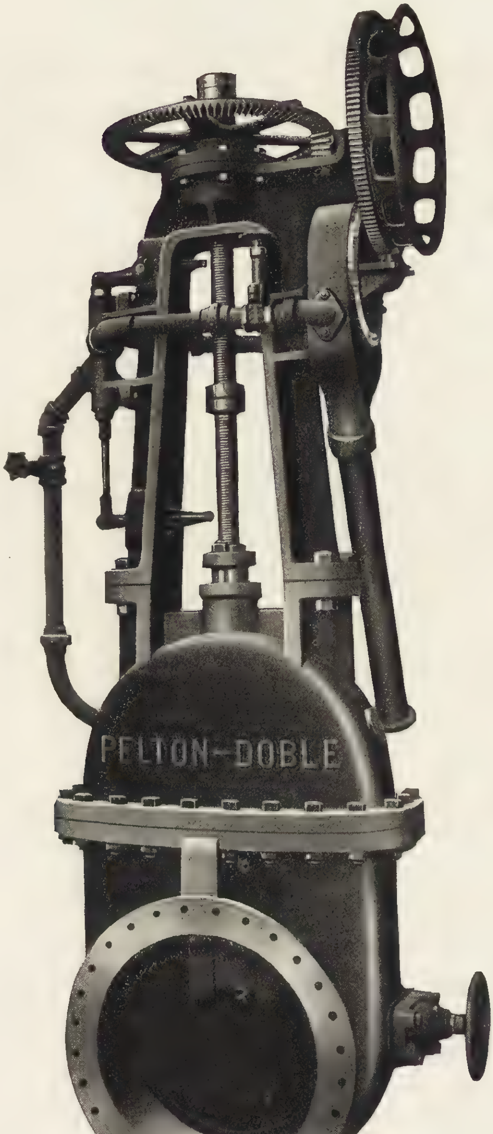

Fig. 23. Single-disc Type Gate Valves, Operated by Reversible Water Motors.

controlled by an hydraulic cylinder, with a terminal slow-closing safety element. This slow-closing safety element consists of an extension of the piston rod which passes into a labyrinth in the cylinder head. The closing of the valve is permitted to take place by discharging the pressure fluid from this cylinder. As the valve approaches the closing position, the extension stem enters the labyrinth shown, and gradually restricts the escape of fluid from the cylinder. This resistance effect is cumulative, so that absolutely no shock or jar can be brought on the pipe line.

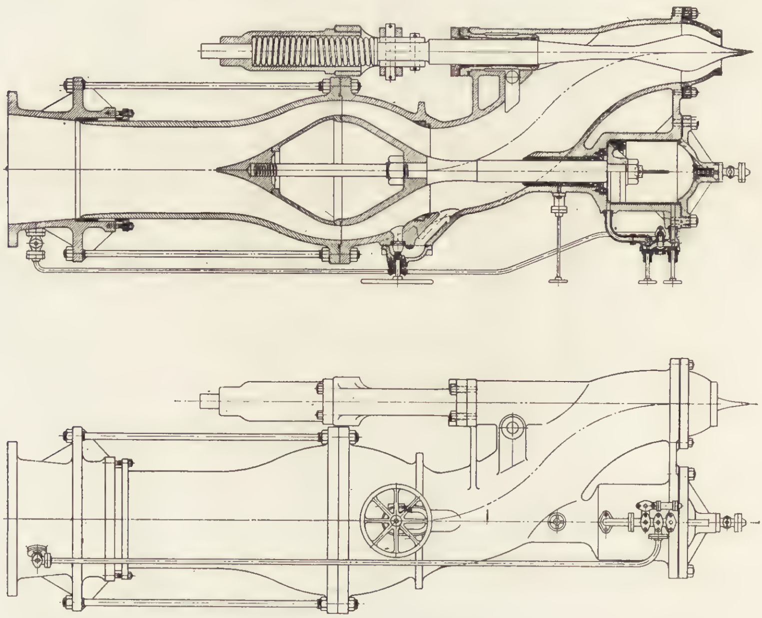

Fig. 24. Uniform-flow Needle Gate Valves Designed for the Largest Size Units Under Extreme Conditions of Head.

From the design it will be observed that owing to the uniform flow through the valve, no eddy currents can form. The seat is of such form that the water flows smoothly over, preventing the cutting out due to eddies forming in the disc type of gate valve. This type of gate valve can also be inspected. This is provided for by the telescopic section of the valve body which can be drawn back into the pipe line, permitting inspection with-

out disturbing any of the parts supported by the foundations. By this method a complete inspection and replacement of all of the working or wearing parts of the valve can be made.

It will be observed that a by-pass valve is arranged so that under normal operating conditions the main valve would be opened with an equilibrium of pressure on both sides of the valve. However, it is designed and constructed so that in case of emergency the valve can be safely opened with the full pres-

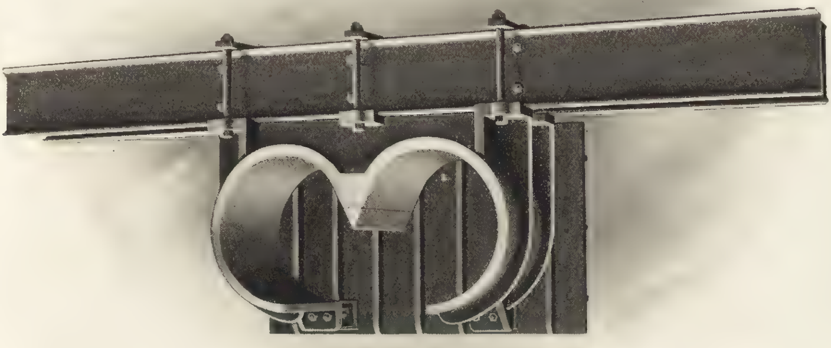

Fig. 25. "Ensign" Vortex Baffle Plate.

sure of water on one side. This type of valve incorporates in its design and construction the elements that are essential for a safe and satisfactory operating valve under the most extreme conditions of high pressure and large power units.

BAFFLE PLATES.

With prime-movers operating under high heads, it is necessary to provide some device to bring to rest the water discharged from the deflecting nozzle when the jet is deflected from the wheel, also to take care of the discharge of the auxiliary relief nozzles where this discharge cannot take place through a free

channel. This problem is an extremely difficult one, but has been most satisfactorily solved by the "Ensign Vortex" type of baffle plate, illustrated in Fig. 25. The action of this baffle plate is similar to that of the Pelton bucket, excepting that the discharge instead of leaving the sides of the bucket, is brought through an angle of approximately 270 degrees, so that the water expends its energy in discharging against itself. These baffle plates have been tested out under heads of water of over 2000 ft. (600 m.) and are absolutely successful in destroying the velocity in the water without commotion, and show practically no signs of wear. The original baffles of this type were installed in the Mill Creek No. 3 Plant of the Southern California Edison Company, which was started March 17, 1903, operating with 1900-ft. (580 m.) head, the wheels developing 1600 horsepower. These baffles are in service today and show practically no indication of wear.

TYPES OF DESIGN.

In general, the most favorable design of hydraulic prime-mover, where the conditions of installation permit, is the single-overhung horizontal-shaft type, the general arrangement being

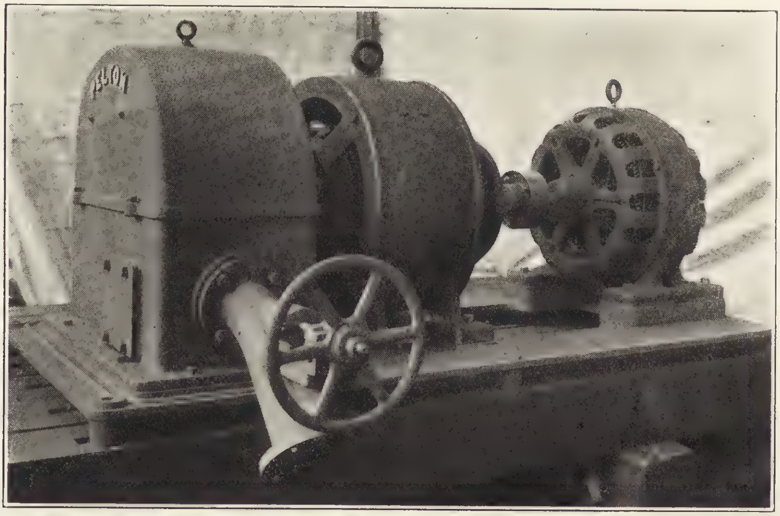

Fig. 26. Characteristic Type of Exciter Unit Used on Large Plants. Operates under 360 ft. (110 m.) effective head at 720 r.p.m., developing 44 hp.

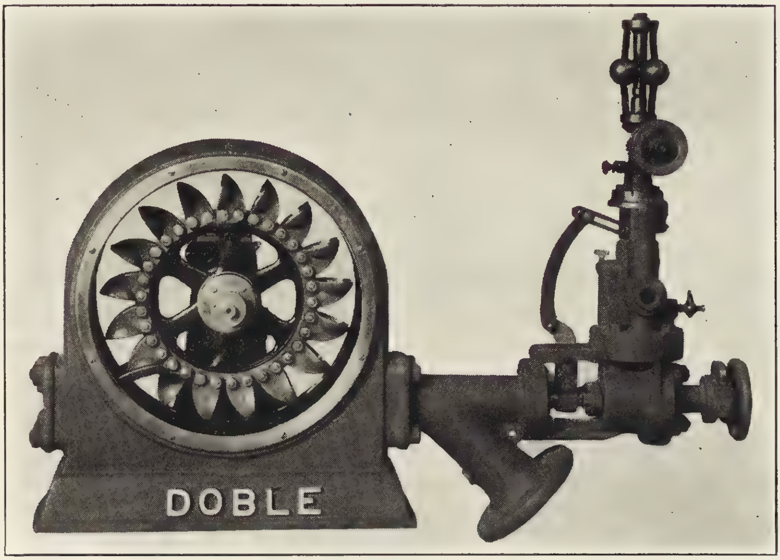

Fig. 27. Small-size Wheel with Direct-motion Governor Mounted on Nozzle Body and Controlling the Needle Direct.

effected by a modification of the detail elements, such as regulating elements, etc., and their mode of operation.

Figure 26 illustrates an exciter unit, consisting of a Pelton wheel driving a direct-current exciter and an induction motor, the power output of the wheel being regulated by a hand-controlled needle nozzle. In the operation of such a unit, sufficient water is discharged against the wheel to carry somewhat more that the excitation load on the generator. This causes the induction motor to act as a generator, discharging into the main bus bars to which the induction motor is connected. This induction motor acts as a speed control, in that it rotates practically in synchronism with the main generators, but has the advantage of some slip, so that speed variation on the main unit is modified due to the slippage of the inductor generator and to the fly-wheel value of the revolving elements of the exciter unit.

A further advantage of this type is that in case of interference, such as clogging of the water-wheel nozzle, which would otherwise bring the exciter to rest, immediately that the power

developed by the water wheel begins to fall off, the induction motor carries the exciter unit. This type of exciter is now being installed in the largest hydro-electric stations and has proven thoroughly satisfactory for the purpose.

A type of Pelton wheel arranged for exciter drive and provided with a direct-motion governor mounted directly on the nozzle is illustrated in Fig. 27. This type of unit is also used for small isolated plants.

An hydro-electric unit suitable for small plants is illustrated in Fig. 28. This shows an ideal two-bearing single-overhung unit, the revolving element of the generator being mounted between the bearings, the water wheel being mounted on one end of the shaft overhanging one bearing, and the fly-wheel being mounted on the opposite end of the shaft, overhanging the opposite bearing. This unit contains a direct-motion governor, ope-

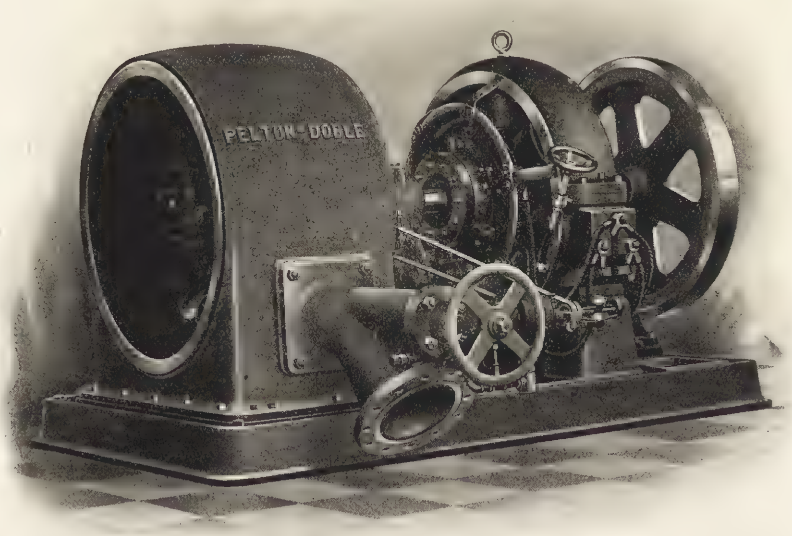

Fig. 28. Typical Single-overhung Horizontal-shaft Type Unit for Small Isolated Plants, Plantation Work, etc. Speed control is by means of a direct-motion governor operating directly on the controlling needle. Operates under 90 ft. (27.5 m.) effective head at 350 r.p.m., developing 18 hp.

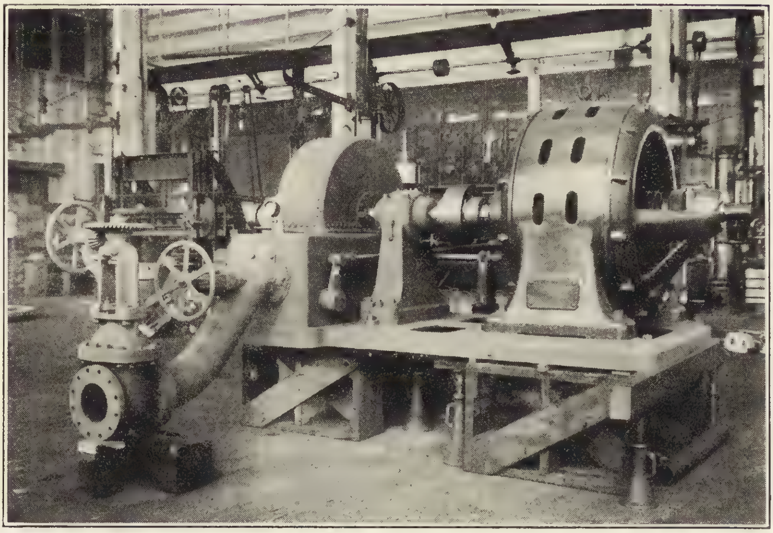

Fig. 29. Typical Hydro-electric Unit for Installation in Small Power Plants. Arranged with needle-regulating nozzle hand control, with governor operating deflecting jet. Operates under 584 ft. (178 m.) effective head at 600 r.p.m., developing 300 hp.

rating the needle direct. In addition, there is an auxiliary hand-control, should it be desired. Units of this type are particularly well adapted to small isolated power plants, such as on plantations and for small towns.

In installations where it is not desirable to vary the quantity of water by the governor operating directly on the needle, the jet-deflecting control is used. A medium-sized unit with this type of control is illustrated in Fig. 29. With this unit the setting of the needle is done by hand, the momentary speed control being secured by the governor operating the jet deflector; units of this type ranging in size from 100 horsepower to 1000 horsepower are very satisfactory in service.

An hydro-electric unit of medium size and involving the most advanced construction is illustrated in Fig. 30. In this unit it will be noted that the speed governor is incorporated within the nozzle construction, and the unit is further equipped with the needle-control auxiliary relief type of nozzle. The unit is arranged with two main bearings, the revolving element of the

generator being placed between the bearings, the water wheel being mounted on one end of the shaft and the fly-wheel on the other. The entire unit is mounted on a combined heavy cast-iron base, securing thereby a most rigid construction. This unit involves all of the improvements of the highest grade large power units.

In the medium and larger sized units, cast-iron base plates are neither necessary nor desirable, owing to the very heavy first cost and weight; and furthermore, as in all large units, it is necessary to depend upon the stability of the foundation construction. In units of this type, the combined shaft which carries the water wheel and the revolving elements of the generator and the bearings are furnished by the builder of the water wheels. An example of this type of construction is illustrated in Fig. 31. The wheel runner is of the disc construction and is bolted against a

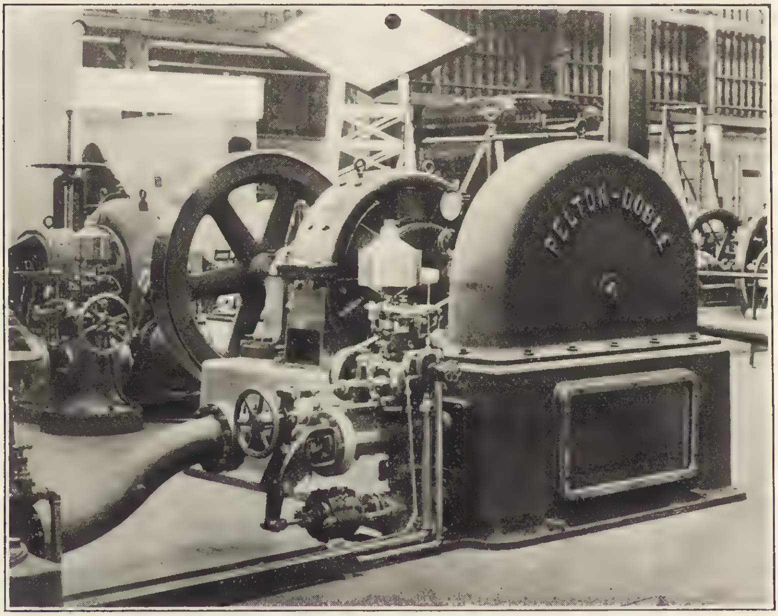

Fig. 30. Ideal Type of Small Horizontal-shaft Single-overhung Hydro-electric Unit Arranged with Needle-regulating Auxiliary-relief Nozzle with Direct Governor Control. Operates under 300 ft. (91.5 m.) effective head at 300 r.p.m., developing 100 hp.

flange forged solid with the water-wheel generator shaft. The bearings are arranged to be mounted on substantial cast-iron base plates, which are bedded directly into the concrete foundations. This type of construction is preferable on all medium and large sized units.

A single-overhung hydro-electric unit of the most modern construction and of large power output is illustrated in Fig. 12. This represents an hydraulic prime-mover now under construc-

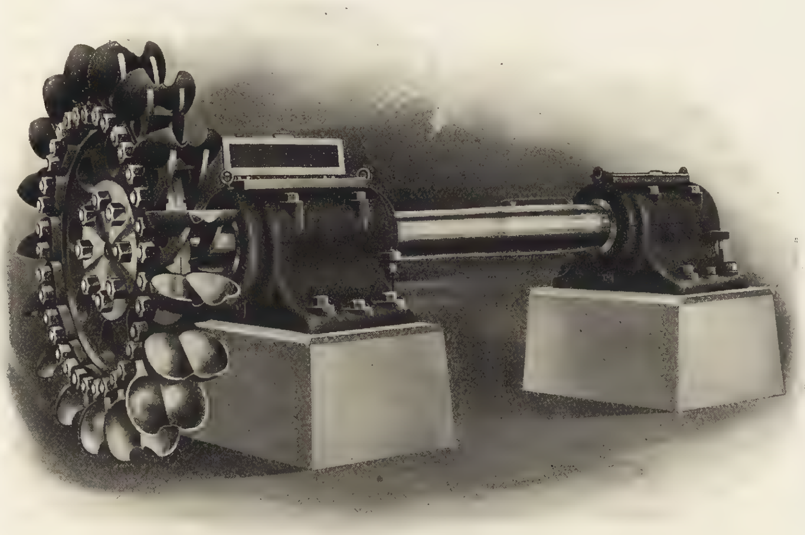

Fig. 31. Single Overhung Horizontal-shaft Construction. Wheel operates under 1200 ft. (366 m.) effective head at 600 r.p.m., developing 1400 hp.

tion, and has embodied in it all of the most recent developments and improvements in the art. In this prime-mover a single jet of water is applied to the buckets of a single wheel, the wheel being mounted on the extreme end of the combined water-wheel generator shaft and being of disc construction bolted directly against the flange forged solid with the hollow chrome-nickel steel oil-tempered shaft. The wheel construction shown in this drawing is of the double-lug type, for the reason that the head of water under which it is to operate, namely, 1650 ft. (500 m.) effective head—with a turning speed of 300 revolutions per min-

ute—secures a favorable ratio between the diameter of the power jet and the pitch diameter of the wheel, so that a thoroughly stable construction could be secured with this type of bucket construction. Were the power output of the wheel larger, it would have required the chain-type or triple-lug construction.

It will be observed that the servo-motor controlling the power output and speed of the unit is carried directly on the power nozzle, the piston of the servo-motor being mounted directly on the extended stem of the power needle; the pendulum head and speed sensitive element with the controlling elements are mounted on the main nozzle body. This unit is arranged to take pressure oil for operating the governor from an independent oil-pressure pumping system.

In addition to the control by the speed sensitive element of the governor, should it be necessary or desirable at any time to control the power output and speed by hand-regulation, it will be observed that a small valve with return mechanism is mounted directly above the servo-motor of the governor. This valve is so constructed with a hand lever that the control of the unit from governor-control to hand-control can be instantly changed by a single movement of the lever operating a four-way valve. On the top of this four-way valve, the hand-control valve is mounted, and is so constructed that by rotating the hand-control wheel, through the means of the floating lever, a corresponding setting of the needle is secured. In other words, if it is desired to carry a half load on this generator, the hand control valve can be set for half position. The power needle will automatically come to this point, and will be maintained at this position until re-set, through the means of the floating lever connections.

A further device installed in the governor of this unit is a load-limiting device, so as to meet the conditions of operations of the power plant, the maximum amount of load which the unit can carry being thus limited. This is of particular importance during seasons of water shortage when it is not desired to have the prime-mover take an excess quantity of water. The arrangement of the auxiliary relief control is secured through the levers as shown in the drawing. The water supplied to this unit is controlled by a single-disc gate valve operated by a reversible water

motor with needle nozzle control. The construction of the centrifugal water disc and collar to prevent the escape of splash water from the housing, is also illustrated. At the extreme end of the shaft is located the spray nozzle for introducing cooling water through the hollow shaft, this cooling water being drawn through the shaft by the vacuum in the wheel housing and discharged into the tail-race.

A further improvement incorporated in this unit, and which has proven to be of great advantage in units located in hot countries, is the arrangement of the tail-race ventilator. This device is so arranged as to take advantage of the partial vacuum that exists in the wheel pit due to the action of the wheel as a blower and the ejector action of the nozzle. Due to this device, the hot air is drawn out of the generator pit and discharged through the tail-race. This type of unit is ideal in every way, and is the preferable one to use wherever the conditions permit of its installation. A number of units of this type of approximately 10,000 horsepower each have been installed, and have proven to be thoroughly satisfactory under the severe conditions of regular operation. The principal advantages of this type are the highest possible efficiency, the simplest form of construction, with the least number of working parts to take care of, while the manner of carrying the shaft gives assurance against the bearings wearing out of line and causing trouble. This type is particularly favorable in the total overall cost of the installed equipment, as it simplifies the pipe fittings and connections, reduces the cost of foundation construction and requires only a single tail-race.

Where the single-overhung type can not be constructed with the power output and speed desired with the available water pressure, the double-overhung type is used; this differs from the single-overhung type in mounting a wheel on both overhanging ends of the combined generator and water-wheel shaft.

The double-overhung type of unit is likewise arranged with two bearings, the revolving element of the generator being mounted between the bearings. A single shaft is used, the rotor of the generator being located between the bearings, with a wheel mounted on each end of the shaft overhanging the bearings. Each wheel is driven by a single jet of water. In the largest

units it would consist of a design similar to that shown in Fig 12, with a second wheel mounted on the opposite end of the shaft.

With the double-overhung type it is possible to make a prime-mover of double the power output, maintaining the same speed of rotation, with the same conditions of water pressure. Where the double-overhung type is used with automatic water-economizing nozzles, it is preferable to mount a separate governor on each nozzle, and in this way eliminate all long governor rock-shafts and connections. The double-overhung type of prime-mover has been installed in a large number of the most important plants, with units ranging in capacity of from 12,000 to 20,000 horsepower.

In those installations where the head of water available is low, as compared with the quantity of water, and where it is desired to maintain a comparatively high speed of rotation, multiple-jet horizontal-shaft type units have been constructed, and under such conditions are thoroughly satisfactory. In this type,

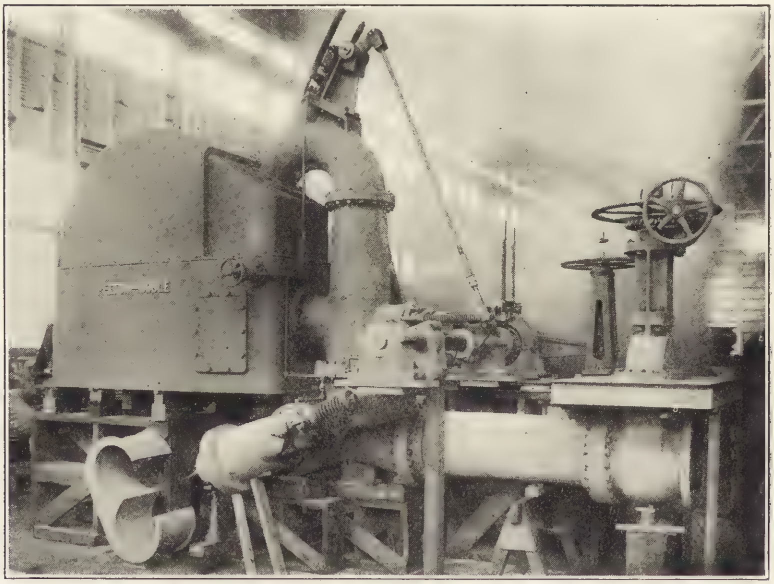

Fig. 32. Horizontal-type Single-overhung Double-jet Wheel with Auxiliary-relief Nozzle, and "Ensign" Vortex Baffle Plate. This wheel operates under 490 ft. (150 m.) effective head at a speed of 300 r.p.m., developing 1900 hp.

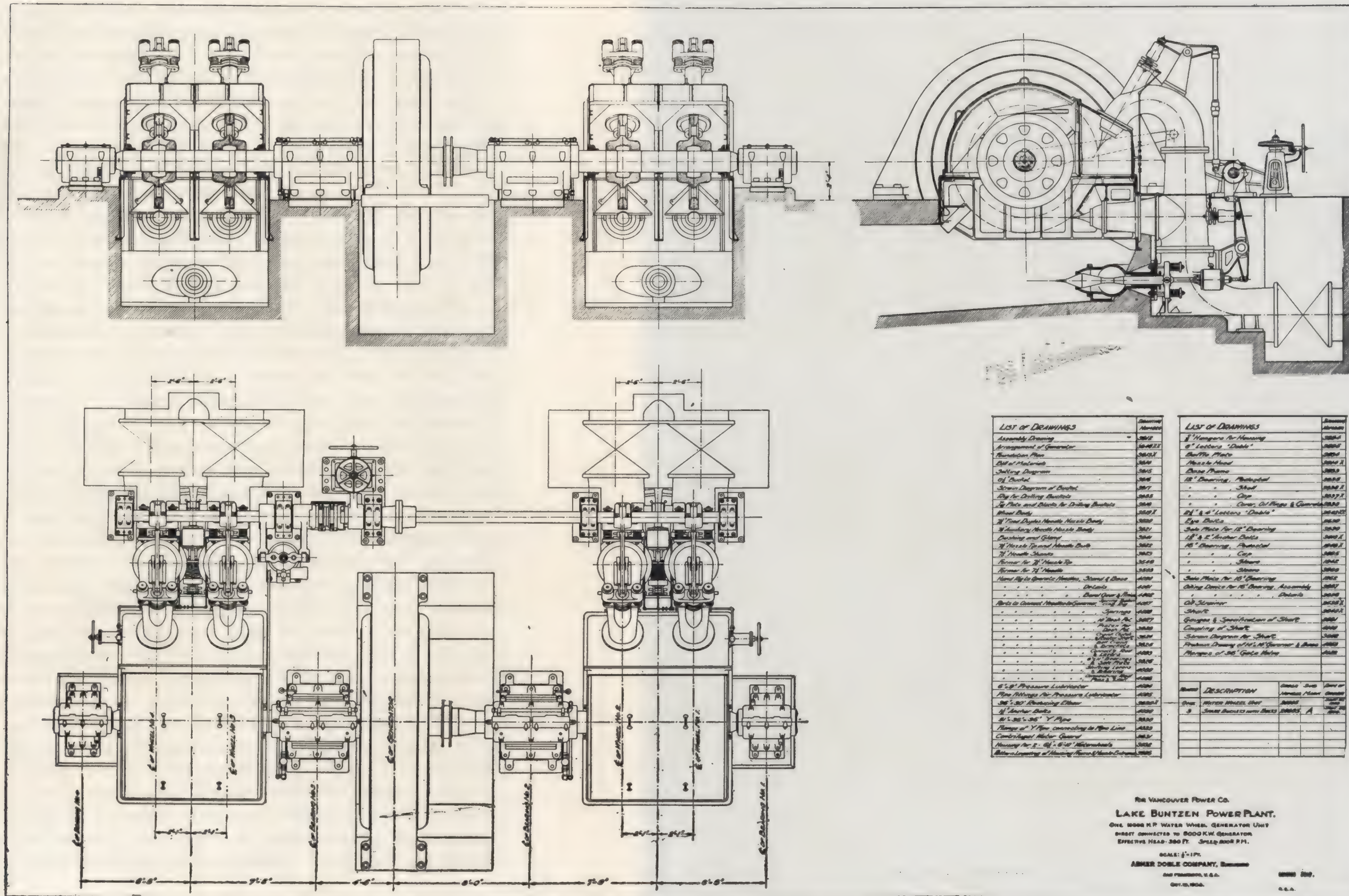

Fig. 33. Horizontal-shaft Type of Unit with Four Wheels and Eight Nozzles. Develops 10,500 hp. under 380 ft. (116 m.) effective head at 200 r.p.m. Arranged with auxiliary-relief-control nozzles.

usually two jets of water are applied to each wheel from the same nozzle body, the jets being approximately 90 degrees apart. This type has been successfully developed with a single-overhung horizontal-shaft unit, with two jets on a single wheel, a unit of this type being illustrated in Fig. 32. In this unit the power output and speed regulation are controlled by the governor operating the needles. An auxiliary relief nozzle is shown attached to one side, discharging against an "Ensign" vortex baffle plate to take up the energy in the jet from the relief nozzle.

Where a single-overhung double-jet unit will not give the power at the desired speed under the conditions of water pressure at the plant, a double-overhung horizontal-shaft type with two jets on each wheel, making four jets in all on the unit, has been developed. In this type the needles controlling the jets to the two wheels are controlled from a central governor through a rockshaft extending across the back of the unit. On each end of this rockshaft a lever is mounted which operates the auxiliary relief nozzle. For larger power units than that illustrated in Fig. 32, a number of very successful units have been built, of from 11,000 to 15,000 horsepower each, using two wheels on each side of the generator, making four wheels per unit; and each wheel is driven by two jets, thus making eight jets in all. This type is especially well adapted where the water is of such character as to be unsuitable for the pressure type of turbines. Furthermore, owing to the high efficiency of the unit, and especially due to the flat efficiency curve, it is much more favorable for overall twenty-four-hour water economy than turbines. In units of this type four bearings are used, the rotor of the generator being mounted between the two main bearings, and at each end of the unit an outboard bearing is provided, the two water wheels being located on the shaft between one main bearing and one outboard bearing. A unit of this type is illustrated in Fig. 33; and Fig. 34 is a 15,000-horsepower unit similar to the one illustrated in Fig. 33, which represents a unit of 10,500 horsepower.

General practice with Pelton hydraulic prime-movers has been to use the horizontal type, as it usually represents the most favorable first cost when taking into consideration the total cost of the plant, including the foundations. It further has the ad-

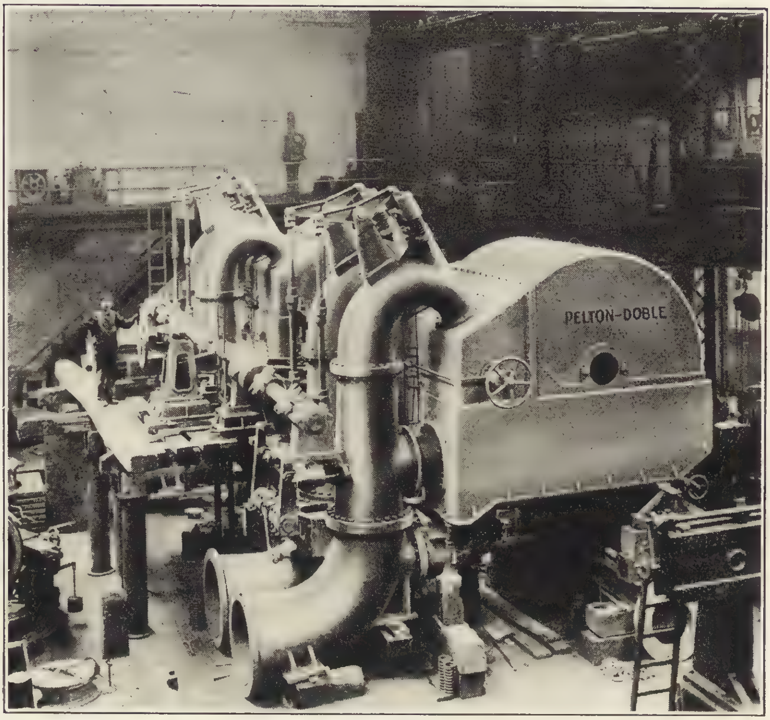

Fig. 34. One of Four 15,000-hp. Units, Horizontal-shaft Type with Four Wheels and Two Jets to Each Wheel. Arranged with auxiliary-relief-control nozzles, operating under 380 ft. (116 m.) effective head at 200 r.p.m.

vantage of simplicity of construction and arrangement of parts available for inspection, lubrication and cleaning. Under certain conditions, however, vertical-shaft types of Pelton hydraulic prime-movers have been installed with excellent results and favorable first cost. This type is especially suitable for comparatively low head plants, where the water contains large quantities of sand, grit or salt and where pressure-type turbines could not be successfully operated. These vertical-shaft units are usually arranged with a wheel runner mounted on the lower end of the vertical shaft, the entire weight of the generator and the wheel runner being carried on a single thrust bearing, the shaft being further provided with vertical guide bearings. With prime-movers of this type, six jets can be installed on a single-wheel

runner; thus developing under a low head a comparatively large power output from a single wheel, and at a favorable speed of rotation.

A modern plant is illustrated in Fig. 35, this being an interior of the Crane Valley No. 1 Plant of the San Joaquin Electric Light & Power Company. These units are 6000 horsepower each, and operate under 1360 ft. (415 m.) head at 400 revolutions per minute. Four units are installed in the plant. These units

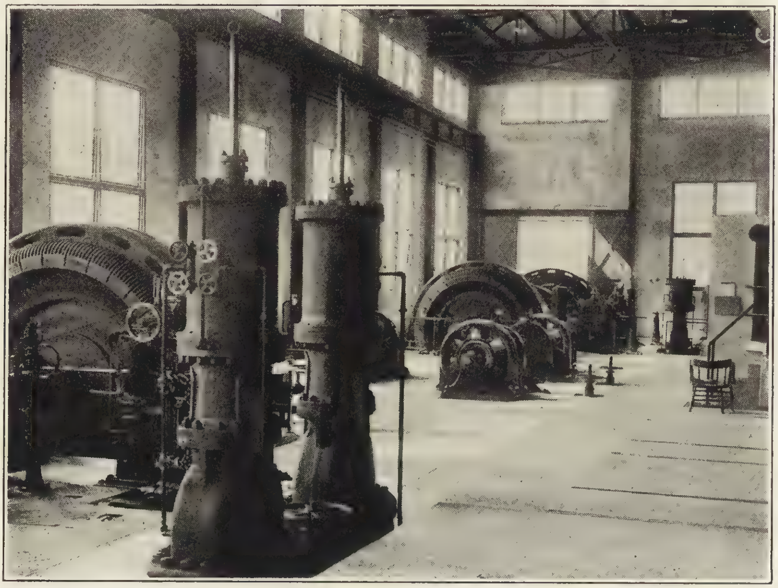

Fig. 35. Interior of the Crane Valley No. 1 Plant of the San Joaquin Light & Power Company, Containing Four 6000-hp. Units. Operates under 1360 ft. (415 m.) effective head at 400 r.p.m., developing 6100 hp. Power output and speed control being taken care of by needle-regulating auxiliary-relief-control nozzles.

are equipped with the auxiliary relief-control nozzles. It will be observed that the gate valves are operated by hydraulic cylinders. These units are of the two-bearing single-overhung type. After this plant was completed a very careful efficiency test was conducted by J. G. White & Company. Figure 36 shows the efficiencies secured on this test. This represents a characteristic efficiency curve from a Pelton wheel.

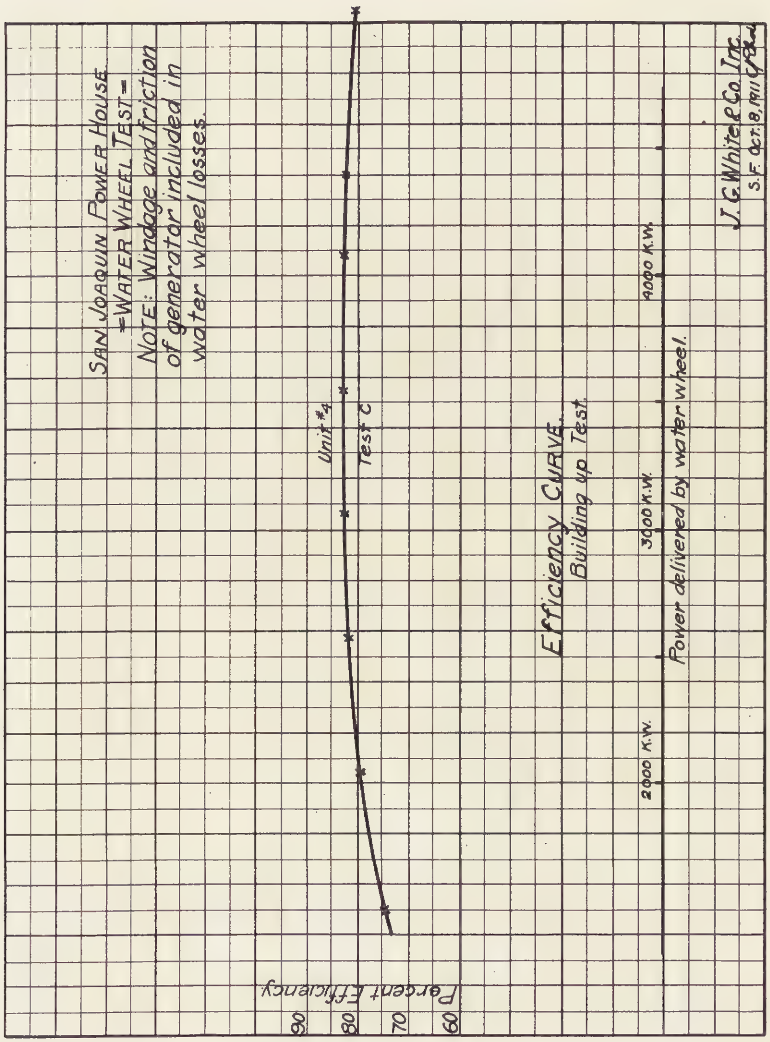

Fig. 36. Efficiency Curves of the 6000-hp. Unit in Crane Valley No. 1 Plant Illustrated in Fig. 35. In conducting these tests, as there was no convenient means of segregating the losses of the generator due to windage and friction, these losses are included in the wheel losses shown by the efficiency curve.

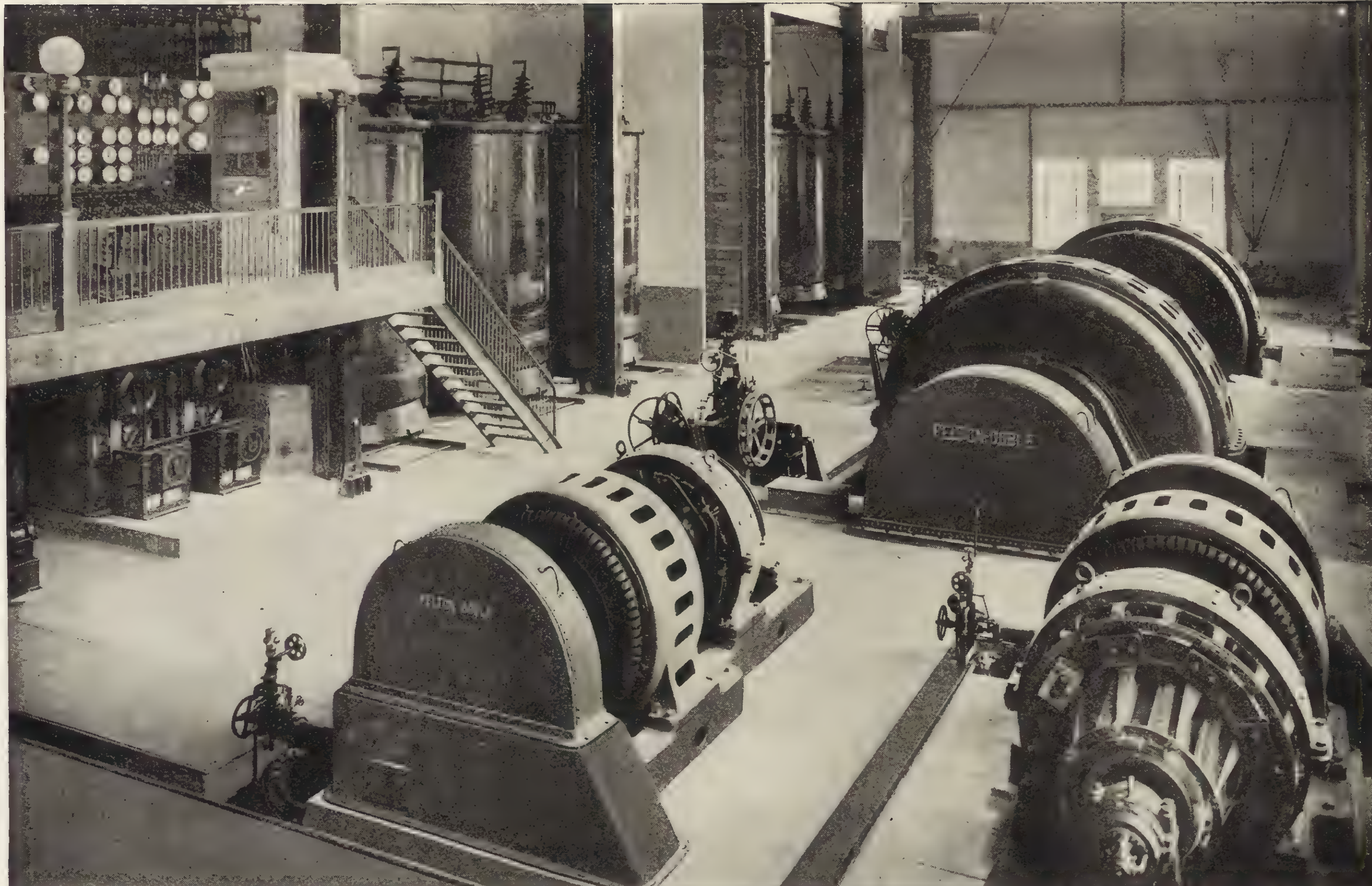

Fig. 37. Drum Power Plant of the Pacific Gas and Electric Company, Showing Two Main Units, and Two Exciter Units and Switchboard Gallery. Two additional units will be installed in 1916. Each unit develops 20,000 hp. under 1330 ft. (405 m.) effective head at 360 r.p.m.

In conducting this test, as it was only possible to segregate the actual electrical losses, and as there were no means for segregating the windage and friction of the generator, these latter losses are included in the efficiency curve.

The most recent plant is the Drum Power Plant of the Pacific Gas and Electric Company, this being illustrated in Fig. 37. In this plant are at present installed two hydro-electric units, double-overhung type, of 20,000 horsepower output each, operating under 1330 ft. (445 m.) head at 360 revolutions per minute. The wheels are of the chain-type construction illustrated in Fig. 4. This plant is equipped with needle-regulating deflecting nozzles, the regulating needles being equipped with remote electric-motor control from the switchboard.

The reason for adopting the needle-regulating deflecting nozzles in this plant was due to the fact that six power plants in series will be installed, taking water from the same source of supply. As there were not available sites in the canyon through which the water canal is carried to install regulating reservoirs, it was necessary to arrange a system of control which would permit of flow of water to the lower plants without momentary interruption. When this plant is completed, it will include four 20,000 horsepower units.

An illustration of the adaptation of the Pelton wheel to a modern mining plant is illustrated in Fig. 38, which shows the interior view of the power plant of the Granby Consolidated Mining, Smelting & Power Company, Anyox, B. C. In this plant Pelton wheels are connected to a large piston blowing-engine, a large piston air-compressor, to three rotary air-blowers of the Connersville type, and also to the electric generators and exciters for the electrolytic process.

It has been the intent of this paper to submit briefly to the interested engineer the principal types of prime-movers that have been developed, with their methods of regulation, and only those types have been described and illustrated which have proven thoroughly reliable and satisfactory under the severe conditions of regular service operation. The art is one that is constantly developing. The limitations as to power output and speed have not as yet been reached and are only limited by the

Fig. 38. Interior of a Modern Mining Plant, the Granby Consolidated Mining, Smelting & Power Company, Anyox, B. C.

The plant consists of three water wheels connected to rotary air blowers of the Connersville type, each wheel developing 775 hp. under 374 ft. (114 m.) effective head, at 115 r.p.m.

Two water-wheel generator units, each wheel developing 1400 hp. under 370 ft. (113 m.) effective head at 400 r.p.m.

One water wheel for motor-generator set, developing 75 hp. under 370 ft. (113 m.) effective head, at 900 r.p.m.

One water wheel for Connersville blowing engine, developing 1400 hp. under 374 ft. (114 m.) effective head at 75 r.p.m.

One water wheel for Nordberg air compressor, wheel developing 800 hp. under 374 ft. (114 m.) effective head at 84 r.p.m.

necessities of the particular installation. As to the limits of capacity, they are restricted only by the profitable demand for the power and by the quantity and head of water available; the only practical limitations as to the head or pressure under which a power plant can be constructed, is the cost of the pressure pipe line.

Plans have been developed which demonstrate that an hydraulic prime-mover, thoroughly satisfactory from the standpoint of first cost, upkeep and reliable operation, can be con-

structed for heads in excess of 6000 ft. in a single drop, and in units as large as 30,000 horsepower each, the limitations being the question of the cost and the difficulties of securing a satisfactory pressure pipe line, an available source of water supply which can be developed at a reasonable cost, and a satisfactory market for the power generated. Other than this, the results to be secured from units of this capacity and operating under these conditions would be absolutely satisfactory in regular operating service. It is not predicted that this represents the limit of capacity or head. It would indicate, however, the approach to a limit, as representing possibly the maximum conditions of a reliable water supply that can be secured within a reasonable cost of development and within a reasonable distance of a profitable market.

The several illustrations which have been introduced in this paper have been selected from regular shop photographic record prints as being the best means of illustrating the general development of the art and improvements in the details of construction and in the systems of regulation, and from this standpoint will be of interest to engineers.

The efficiency to be secured from an Impulse Prime-Mover is affected by the type of the unit, the head or pressure that it is to operate under, and the speed of rotation; these factors determining the ratio of the jet and the pitch diameter of the wheel.

A characteristic efficiency curve, showing the results from a medium sized prime-mover under actual operating conditions, is shown in the efficiency curve of the Crane Valley No. 1 Power Plant, Fig. 36.

Under exceptionally favorable conditions the efficiency of a Pelton hydraulic prime-mover will range between 83% and 86%, depending upon the special limitations of the installation. It is anticipated that these extremely favorable efficiencies will be somewhat improved, and with heads in excess of 3000 ft. with large sized power units, it is reasonable to predict an efficiency of approximately 90%.

In considering these questions of efficiency, it must be appreciated that they are based upon the prime-movers installed in

actual operating plants and on the basis of regular commercial service, and represent the total overall efficiency of the prime-mover.

DISCUSSION

Mr. L. E. McCoy,* Assoc. A. I. E. E., opened the discussion by asking if any comparative tests had been made of single- and double-nozzle water wheels. He had run a test which apparently had given ten percent more efficiency for a single nozzle than for two with the same runner. Mr. McCoy.

Mr. W. A. Doble,** M. Am. Soc. C. E., said that something was presumably wrong. He had recently tested a wheel with six nozzles with good results. Allowance was made for windage and friction, and the efficiency was uniform regardless of the number of nozzles. There was no reason why multiple-nozzle wheels should not give good efficiency, unless the wheel was improperly designed. In Europe, double-jet wheels are quite common, adapted largely from the design of a plant which the Abner Doble Co. had constructed in India, and which had been so designed as to get the proper speed. In theory and practice there is very little difference in the efficiency of single-jet and multiple-jet wheels. Mr. Doble.

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